Frontiers of particle beams: observation, diagnosis, and correction

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Very recently, we became witnesses to one more triumphant success of extremely high energy accelerator physics. The Large Electron-Positron Collider (LEP) was put in operation at CERN in the summer of 1989, on which remarkable results on accurate measurement of the widths of neutral Z-bosons were obtained after two months that enabled one to obtain a clear indication that the number of kinds of quarks and leptons equals three. This and previous outstanding successes such as the discovery of the c-quark and the W-boson became possible only due to a very high level of development of accelerator physics and technology. A well developed, branched network of short-term schools and working conferences on accelerators both in North America and also at CERN is furthering this to a great extent.

The reviewed collection of articles has been compiled from the materials of the third in a series of special schools on accelerators organized jointly in the U.S.A. and CERN. The first of these courses was devoted to nonlinear dynamics and their application in accelerator physics. This school took place in Santa Margarita di Pula, Sardinia in January 1985, and its proceedings were published in Vol. 247 of the "Springer Lecture Notes in Physics." The second school, which took place at South Ladre Island, Texas, in October 1986, was entitled "The latest news on charged particle beam physics" and served as an introduction to modern concepts in the physics and technology of particle accelerators. These proceedings comprise Vol. 296 of the "Springer Lecture Notes in Physics."

Vol. 343 that is being reviewed of the indicated series of lecture notes came into being as a result of holding the latest of these schools, which took place at Anacapri on the island of Capri, Italy, from October 20 to October 26, 1988. Methods of observation, diagnosis, and correction of the properties of charged particle beams during their acceleration, and of the circulation in accelerators and storage rings, a question which did not get extensive discussion in the past, were considered at this school.

The program of the school included lectures on three main themes:

Phenomena that are used for observing a beam,
Single-particle parameters, and
Collective parameters.

Each of these themes was preceded by one or more general lectures, after which detailed lectures followed on special questions, such as Schottky noise, closed orbits, or impedance measurements. The objective was set to show how to observe diverse beam behavior, how to interpret and classify these observations, and then, how to control or correct the corresponding parameters. The program of lectures was supplemented by three seminars, at which future monitoring at electron-positron colliders and special questions of nonplanar machines and of the experimental tracking of particles were considered.

In G. Gründer's paper "Accelerator physics as a profession" which opens the symposium, the interdisciplinary and international nature of this complicated field of science, which is based on the extensive use of classical and quantum mechanics, electromagnetism, and of statistical physics, and which also relies on the leading technology of the world, is emphasized. The author singles out two types of accelerators for conducting scientific research. World class facilities with unique characteristics and possibilities belong to the first type. Regional facilities which provide the possibility of conducting research for a considerably larger number of experiments form the second, more numerous group.

R. Tallman in his introductory lectures reminds us of the main conclusions of the general theory of linear three-dimensional motion of a single particle in the magnetic fields of accelerators. An examination of betatron motion is carried out in six-dimensional phase space by using a matrix formalism. The possibility of conversion to two-dimensional motion is investigated. The generalized Twiss parameters are described and a method is shown for finding the eigenvectors and fundamental frequencies. The connection between lateral and longitudinal motions and methods of compensating for it are analyzed. Bound lateral motion is examined in more detail in L. Teng's paper.

The checking and control of the position of a closed orbit and of the betatron oscillation frequencies are among the most important problems for any system of controlling an accelerator. A significant increase of the dimensions of accelerators and their operation in a collider regime impose rigid limits on the deviation of these parameters from the design ones. A high quality for a closed orbit is exceptionally important for the efficient operation of an accelerator and for obtaining a low background on the experimental detectors. Zh. P. Kuchuk's paper is devoted to methods of measurement and correction of the distortions of a closed orbit in cyclic accelerators. The effect of magnetic structure defects on a closed orbit and methods for improving an orbit are discussed. The contribution of the energy spread to the position of an orbit is examined. Methods to minimize trajectory deviations in the lines for transporting the beams and minimizing the amplitudes of betatron oscillations during injection are described. A method of orbit correction by observing a specially formed thin particle beam was widely adopted.

Measurement of betatron oscillation frequencies is the main diagnostic tool for optimizing the process of particle injection and extraction and also the entire operation of the accelerator as a whole. Such measurements are important for checking and correcting the actual magnetic structure of the accelerator, for identifying dangerous resonances, and for determining local values of the betatron functions. M. Serio describes methods of frequency measurement by investigating the response of the beam to the excitation of lateral oscillations by a local, rapidly changing external field. A beam position sensor is an integral part of the measurement system.

Electromagnetic devices which draw off a small amount of energy from the beam without exerting a significant effect on it mainly serve as the monitors of particle beams in accelerators. Traditional methods of observing a beam by means of electrodes with slots, and so-called electrodes in the forms of a button, strip lines, and resonator and magnetic induction sensors are described in fair detail in papers by M. Serio, A. Hoffman, and G. Lambertson. These devices enable one to measure the current of a beam, its position, and its shape. Short longitudinal electrodes are used to measure coherent synchrotron oscillations, the longitudinal dimensions of clusters, and the distances between clusters.

Synchrotron radiation has already been used for a long time to measure the lateral dimensions and time structure of electron beams, their angular divergence, and, consequently, also their emittance. And undulator radiation, which is preferable to syhnchrotron radiation in a number of cases, has also started to be used recently for this purpose. Optical methods of diagnosis from magnetic bremmstrahlumg are examined in papers by A. Hoffman and R. Barbini *et al.* (also see Ref. 1).

Along with transparent places for observation in linear accelerators, overlapping beam monitors are convenient in the transport channels between accelerators in one-revolution regimes of operation of cyclic accelerators. R. Yung gives a review of such monitors, whose actions are based on the phenomenon of luminescence, transition radiation, secondary electron emission, the generation of secondary particles or the process of bremsstrahlung, and the ionization of residual gas or of special gas jets.

In connection with the increasing requirements for intensity, collective effects caused by the space charge of the beam are acquiring more and more importance. The main longitudinal and lateral collective effects and the instabilities caused by them are examined in the lectures by R. D. Root and R. D. Cauhaupt. Moving charged clusters generate induced electromagnetic fields in the medium surrounding the beam, which exert feed-back on the beam. The effect of wake (trace) fields on longitudinal and lateral motions is investigated in detail. Single cluster and multi-cluster regimes of operation are examined for linear and cyclic accelerators. Interaction of the particles inside a cluster is typical in the first case; in the second case, there is an interaction of a sequence of clusters. Collective effects can lead to increases of the lateral sizes and lengthening of the clusters, to a change of energy within a cluster, to the appearance of a large spread of energy from cluster to cluster, and to a shift of a cluster with respect to the phase of the accelerating voltage. Much attention is allotted in the collection of articles to methods for reducing the effect of wake fields. Among them are: reducing the number of clusters, reducing the frequency of the accelerating voltage, the design of special accelerating structures, and optimizing the phase of the accelerating voltage.

The paper by L. Palumbo and V. G. Vassaro is completely devoted to measurements of wake fields and impedance; in it, the latest data on the direct measurement of induced fields by means of charged particle beams are presented, and a review of electronic measurement methods is given.

Schottky in 1918 decribed the statistical fluctuations of current that are caused by a finite number of charge carriers. These fluctuations are often used to study the operation of both cyclic accelerators and also strorage rings. Diagnosis by using Schottky noise is discussed in S. van der Meer's paper and in a number of others. The observation of longitudinal Schottky signals is used to find the distribution of particle revolution frequencies, and also the total number of particles in a circulating beam. The lateral signals that are obtained during the difference switching of electrodes are used to measure the dependence of the emittance on the frequency of revolution. Special attention is allotted to measuring the Schottky noise from a grouped beam.

D. Busar explores the analysis and processing of signals from the sensors of the diagnosis and correction system. Frequency analysis and signal filtering are discussed. The requirements for a broad band response of the signal electrodes are considered. They become fairly rigid for processing Schottky signals in stochastic cooling experiments.

Energy and luminosity are the basic parameters of facilities with colliding beams. R. Johnson considers methods for measuring luminosity and energy for electron-positron and proton-antiproton colliders. Elastic scattering of colliding particles is used to measure luminosity. The dependence of luminosity on the cluster parameters and the magnetic structure of the storage rings is discussed. Accurate calibration of the energies of the beams is extremely important for electron-positron colliders, since it directly determines the accuracy of measuring the masses of the particles that are formed upon collision. The precision method of resonance spin depolarization, which has been described in more detail in Ref. 2, gives record accuracy.

The paper by M. Plasidi is devoted to the problem of obtaining and retaining polarization in large electron-positron storage rings. The motion of electron spin in a magnetic field, methods for controlling spin orientation, depolarization mechanisms, and the principles of Compton polarimetry are discussed.

In a final paper that is not at all usual for such symposia, G. Voss tells of an experiment for starting up very large electron accelerators and storage rings. He took part in the operations on the start-up of the Cambridge electron synchrotron; at present, with his decisive participation, the start-up of the first electron-proton collider in Hamburg is being achieved. The procedure for fine tuning an accelerator, methods for finding and removing technical errors, and the difficulties which are encountered here are described. The role of instabilities is emphasized. Working accelerator physicists will find here much that is instructive and familiar.

As a whole, the collection of articles under review reflects fairly completely the modern level of development of methods for observing and controlling charged particle beams at the largest accelerator facilities. A large volume of information is contained in it which may prove to be useful in the design, construction, and start-up of accelerators.

[1]D. F. Alferov, Yu. A. Bashmakov, and P. A. Cherenkov, Usp. Fiz. Nauk **157**, 389 (1989) [Sov. Phys. Usp. **32**, 200 (1989)].

[2]A. N. Skrinskii and Yu. M. Shatunov, Usp. Fiz. Nauk **158**, 315 (1989) [Sov. Phys. Usp. **32**, 548 (1989)].

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