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Measurement of the Beam Current in the 6-GeV Electron Synchrotron DESY Utilizing the Synchrotron Radiation

by

R. Haensel and B. Sonntag
Physikalisches Staatsinstitut, II. Institut für Experimentalphysik der Universität Hamburg, Germany

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MEASUREMENT OF THE BEAM CURRENT IN THE 6-GEV ELECTRON SYNCHROTRON DESY UTILIZING THE SYNCHROTRON RADIATION

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For many measurements with an electron synchrotron it is necessary to know the number of particles circulating in the accelerator. There exists, in addition to various electrical methods of current determination, an optical method which is based upon a measurement of the intensity of the synchrotron radiation given off by the electrons.

It is well known that electrons radially accelerated by a magnetic field emit synchrotron radiation and that the intensity of such radiation increases with electron energy. Synchrotron radiation establishes an upper limit on the energy attainable in a circular electron accelerator. Characteristic properties of synchrotron radiation in addition to its high intensity are a continuous spectral distribution, a high degree of polarization and a narrow angular spread around the direction of electron motion. These properties have been quantitatively calculated by several authors[1,2] and experimentally confirmed[3,4,5]. With increasing electron energy the spectral maximum is shifted to ever shorter wavelengths, while the intensity of the long wavelength radiation increases only a little. The maximum lies in the ultraviolet for 100-MeV electrons and for electrons in the GeV range has shifted downward into the X-ray region.

A possibility for the measurement of the current is the comparison of the intensity of the synchrotron radiation in the visible spectral region with that of a black body. In this case, however, it must be remembered that the two different sources have different properties, namely the spectral distribution, angular distribution, and polarization. In addition the synchrotron radiation is pulsed while the standard lamp burns continuously.

DESY is a 6-GeV electron synchrotron of the AG-Type with a magnetic radius of 31.7 m, a total circumference of 316.4 m, an acceleration period of 10 msec, and a repetition frequency of 50 Hz during which about 10^{11} electrons per pulse may be accelerated.

It is important for our measurements that while many of the injected electrons are lost in the first revolutions the number of electrons does not change for the remainder of the acceleration period.

Near the connection of a beam pipe that has been mounted for synchrotron radiation experiments in a remote experimental area there is the possibility of reflecting out of the vacuum chamber by means of a mirror the light necessary for our measurement (Fig. 1). This beam pipe lies on a tangent to the electron orbit. On an extension of this tangent there is a second short tube to remove reflected light from the vacuum chamber wall originally lying on the tangential point. This extension is capped for our measurements with a glass window. Outside this window the standard lamp is mounted. In this manner nearly identical optical paths are established for both sources. They have only an angle of 30' of arc between their directions. A tungsten ribbon lamp (Philips type W40) serves as the standard lamp.

Because of the different polarization properties of the two sources and the polarization dependence of the mirror reflectance a polarization filter is utilized. It was experimentally established that the exit window is optically inactive. A narrow band at 5870 Å is taken from the spectrum of both sources by means of an interference filter. Reflections which come from other parts of the vacuum chamber wall have a direction different from that of the direct light and are suppressed by means of baffles in the intermediate image. A slit in front of the photomultiplier cathode limits the illuminated area in order to minimize errors due to the variation of sensitivity over the photocathode.

The signal from the photomultiplier passes through an electronic gate synchronized to the machine cycle which removes the pulses resulting from fluorescence of the vacuum chamber walls due to the loss of electrons at injection and ejection. As this gate is also in service during operation of the standard lamp the effective pulses from both sources are the same. After the gate the pulses go to a ratemeter and are then displayed on a meter as the average current in the accelerator.

Because of the stability with time of the electronic equipment and the high intensity of both sources the use of a nullmethod (e.g. a rotating mirror) is not necessary. It is only necessary to check the calibration with the lamp from time to time during interruptions of the accelerator operation.

A gradual darkening of the portion of the mirror (made of stainless steel) which is irradiated by the X-ray part of the synchrotron radiation limits the accuracy of the measurements. Since the two sources have different angular distributions this darkening affects the signals to be compared in different ways. It is therefore necessary to measure quantitatively the pattern of the darkening and evaluate numerically the effect.

The measurement of the profile of darkening is performed with the standard lamp and by means of a shutter which is mounted in front of the mirror and which can be vertically positioned from outside the vacuum chamber. A further error is introduced by the uncertainty of the measurement of the standard lamp temperature, mainly because (for reasons of intensity) the entire 20 mm long tungsten ribbon is utilized and the temperature variation over the ribbon can be 40°.

After installation of the measuring apparatus it offered in comparison to the electrical method (with induction coils and electronic amplifiers) in addition to simpler operation a higher accuracy and long run reproducibility.

The total error is estimated to be 10 % with a new undarkened mirror and 15 % for a darkened mirror for which the darkened area has been analyzed.

Since theory makes quantitative predictions of the intensity not only in the visible spectrum (the basis of our measurement method) but also in other spectral regions an electron synchrotron may be used as a standard source, for example in the vacuum ultraviolet region where the intensity of the black body is too low. Plans exist to carry out standardization of vacuum ultraviolet sources[6] and absolute measurements of the photo- or fluorescence yield of metals and phosphors with the help of this arrangement.

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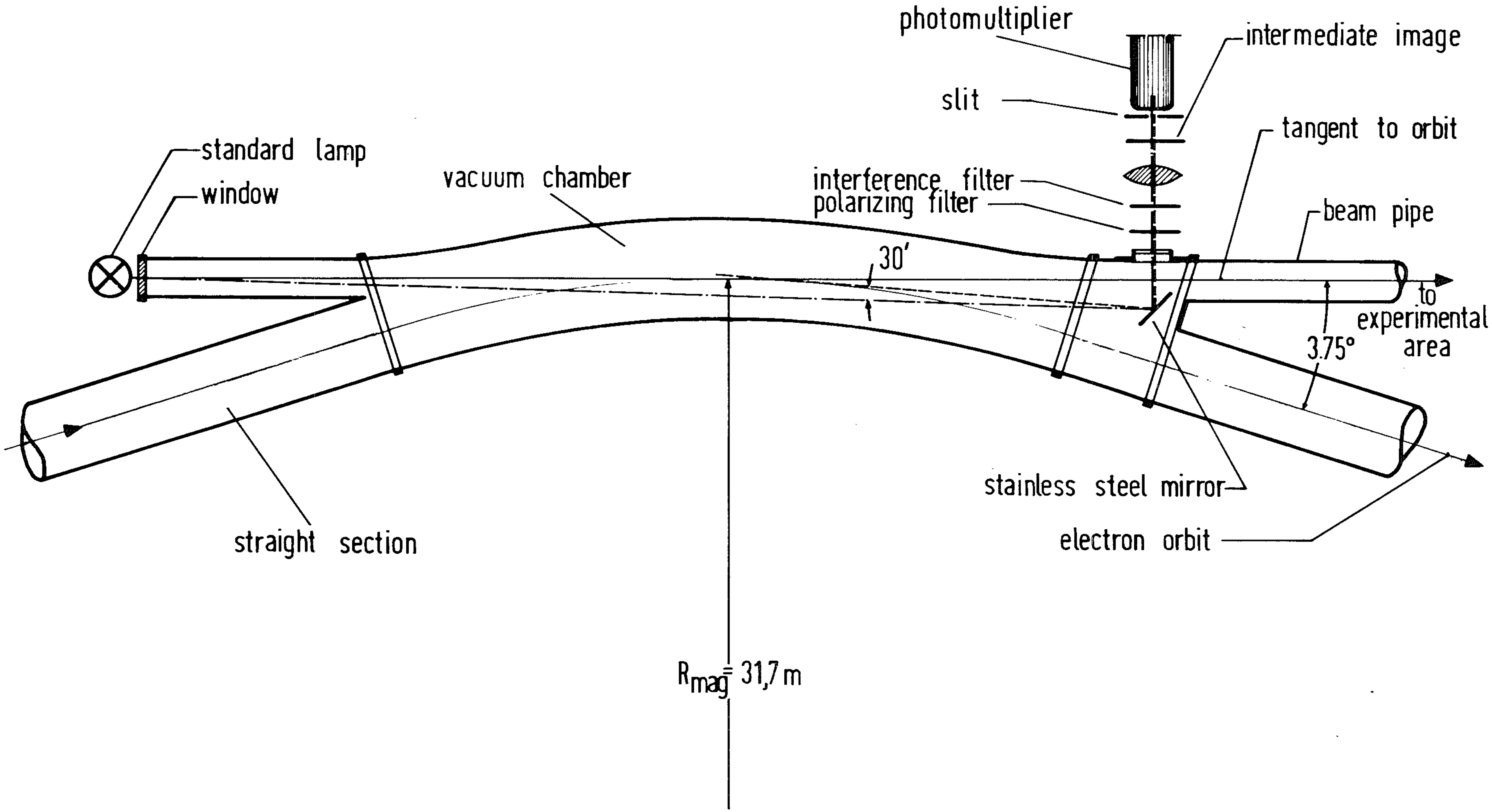

Fig. 1 Experimental arrangement for the measurement of the absolute electron beam current

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