A FACILITY FOR HIGH-PRECISION ABSOLUTE ENERGY MEASUREMENT USING THE K-EDGE ABSORPTION PHENOMENON FOR LINEAR ACCELERATORS

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1. ABSTRACT

A simple facility for absolute energy measurement with an accuracy of $\Delta E \le 10^{-4}E_0$ by direct measurement of the bend angle in a high-precision-mapped magnet dipole used for beam transportation system by two opposite short (about 2 mm long) high-field-intensity permanent magnets installed at each end and creating two swaths of hard x-ray synchrotron radiation for electron accelerators and recirculators is presented.

Two perfect crystals mounted on a platform symmetrically with respect to the axis of rotation and keeping parallelity of their reflecting planes are used for diffraction of a narrow (horizontal divergence of the swaths at chosen wavelength is about 10^{-5} rad) hard x-ray beams in the bending plane.

By rocking the platform, one can reach a point of observation of K-edge absorption for a chosen substance at each SR beam.

It is shown that the rocking angle of the platform measured with an accuracy of a few arc sec is equal to the bend angle of the electrons.

The limitation of the accuracy of absolute energy measurement for the entire installation by the sources of statistical and systematic error are discussed.

2. INTRODUCTION

In the last few years several methods of high-precision and non-destructive absolute beam mean energy measurement have been proposed. The first is energy calibration by measuring a frequency of the resonant spin depolarization of a transverse polarized orbiting beam in an electron storage ring using a laser polarimeter [1]. This method, which can be used for circular accelerators only, has a resolution of a few units of 10^{-5}, mainly limited by electron energy spread.

Two more methods of absolute energy determination are based on a measurement of the vertical distribution of synchrotron radiation [2] and a non-linear variation of SR spectral distribution on beam energy in two bendings having different magnetic field intensity [3]. These methods also have a resolution at the level of a few units of 10^{-5} and can be used for linear or circular accelerators. The facilities necessary to perform these methods are simple and uses a conventional x-ray technique: monochromators, differential ionization chambers, a system of high-precision remote control slits and a short (about 0.1 m long) three pole wiggler.

Another method is the spectrometric method, for which the best performance was obtained at the SLC energy measurement facility [4]. This facility measured the bending angle using two SR swaths created in two short kicker magnets having magnetic fields perpendicular to the field direction in the main bending magnet and installed on its sides. The main source of systematic errors limiting the accuracy of energy determination at the level of 5×10^{-4} is nonorthogonality of the vectors of the magnetic field strength in the kickers and in the main bending dipole [5].

In this paper a facility of bend angle measurement in a spectrometric magnet using the K-edge absorption technique proposed in [6] and free of the above-mentioned strong limitation is presented and discussed. The facility has been designed for a medium energy electron beam (0.5 – 4.0 GeV) and adapted to the parameters of a beam transport line of the Yerevan Electron Synchrotron and CEBAF.

3. THE METHOD

The concept of the method is the following. A beam of electrons passes through a high-precision mapped dipole magnet having a field average intensity $\overline{B_b}$ and two short dipoles having opposite direction of field intensity $B_s >> \overline{B_b}$ installed on its side (Fig. 1).The field direction in short magnets is orthogonal to the orbit plane. The synchrotron radiation generated in the main dipole and short magnets has different spectral distribution defined by corresponding critical wavelengths λ_{c_b} and λ_{c_s} which can be determined as: λ_c (cm) = $7.12 \times 10^3 / \gamma^2 B$(Gauss) where γ is Lorentz factor.

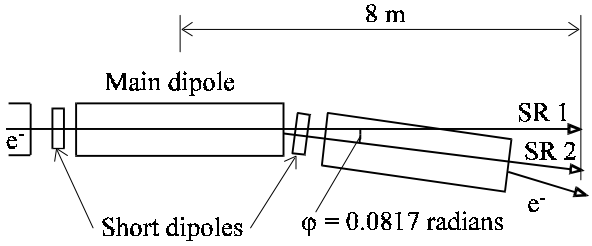

Fig. 1. The layout of the magnets; the distance and angle shown are CEBAF examples.

These critical wavelengths are chosen to satisfy the condition $\lambda_{c_b} >> \lambda_{c_s}$. So these magnets are working as magnetic targets, generating wavelength λ_0, which is practically not represented in the spectrum radiated from electrons in the main dipole.

The principle of the method is as follows. Two K-edge absorption spectrometers (1) are mounted on a platform (2) installed on a shaft of a goniometer symmetrically to the axis of rotation and keeping parallelity of the reflecting planes of a crystals (see Fig. 2).

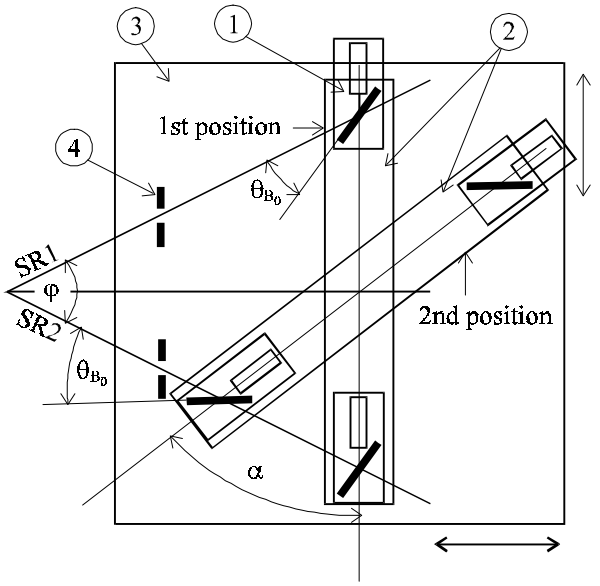

Fig. 2. The scheme of absolute energy measurement with rotating K-edge spectrometers

The rotation is performed by a remote control, high-precision, one-axis θ-2θ goniometer installed on a remote control microscopic scanning table (3). The SR swaths generated in the short dipoles cross the center of the input slit (4) of the spectrometers when the platform is positioned perpendicularly to the central line (bisector) between two swaths. The input collimators are mounted on the 2θ - hand of the goniometer and can be accurately adjusted against the spectrometers. Rocking the platform each spectrometer can be tuned up at a wavelength λ_0 between the upper and lower borders of K-edge absorption of a chosen element. This rocking angle α between two positions of the platform where the points of the absorption curve are reached by the spectrometers is equal to the beam bend angle φ in the main bending magnet. This is the goal of the method because absolute energy is determined as $E = \frac{c}{\varphi}\int^{\Delta l} Bdl$.

4. SYSTEMATIC AND STATISTICAL ERRORS

4.1 Spectrometer

The spectrometer consists of a one-crystal Si(111) monochromator, x-ray detector (NaJ scintillator and photomultiplier), an absorber plate (Cu or Mo) and an input collimator. A necessary degree of monochromatization, ΔE_γ, by one-crystal monochromator have to be reached due to small divergence, Δθ, of SR beams according to formulae: $\Delta E_\gamma = E_{\gamma 0}\, \Delta\theta \tan^{-1} \theta_B$, where θ_B is Bragg angle and $E_{\gamma 0}$ is the monocromatized photon energy. Therefore there is not needing of an output collimator and its $2\theta_B$ rotation around the axis of the crystal. An accuracy, δθ, of an angle measurement using K-edge absorption spectrometers is limited by several parameters. One of them is an intensity drop gradient between the upper, $N_{\gamma u}$ and lower, $N_{\gamma l,}$ points of an absorption curve $G=(N_{\gamma u} - N_{\gamma l,})/\Delta\Theta$, where ΔΘ is the angular distance between upper and lower points of the absorption curve. The next is intensity fluctuation at the upper border of absorption $N_{fl}.= (N_{\gamma u})^{-2}$. So, the accuracy can be determined as: $\delta\theta = \Delta\Theta / N_{fl}$. For the spectrometer having 2 eV energy resolution at $E_{\gamma 0}$ = 8.98 keV the angular distance ΔΘ is equal to 5.5×10^{-4} rad. With the purpose to have 2 eV resolution the SR beam divergence has to be 5.5×10^{-5} rad. In this angular interval the intensity radiated from electron beam of the energy of 2 GeV and current 10^{-5} A in magnetic field of the short magnet having B_S=2 T is $N_{\gamma u}=2.532\times10^6$ photons per sec. According to above bringing formulae the angular resolution limited by the spectrometer is $\delta\varphi_1=0.35\times10^{-6}$ rad. So, the input collimator having the width of 0.4 mm and installed at 8 m downstream from the short magnet is necessary.

The spectrometer is constructed using standard x-ray equipment.

The next source of statistical error, $\delta\varphi_2$, is caused by nonparallelism of the reflecting planes of the crystals in both spectrometers. The necessary parallelism can be achieved by tuning the spectrometers at wavelength λ_0 using one of the SR swaths. For that, after tuning of the first spectrometer the platform has to be turned on an angle π and the same procedure mast be performed for the second one. So, this error is: $\delta\varphi_{2,} = 0.35\times10^{-6}$ rad.

4.2 The alignment of the spectrometers

The next source of systematic error is caused by non-coincidence of the SR beam centroid with the center of the corresponding input slit of the spectrometer.

This adjustment has to be performed using a microscopic remote control table (3) as follows (See Fig. 2). Scanning the table in a direction orthogonal to the central line of SR swaths, one can achieve an equal intensity passing through the slits. Then, scanning the table along the central line, the maximum of the intensity and its equality can be reached. This means that the center of both input slits coincides with the centroids of the SR swaths. The intensity of the beam passing through input slits and their equality have to be measured by two ionization chambers (5) installed behind of the slits (Fig.

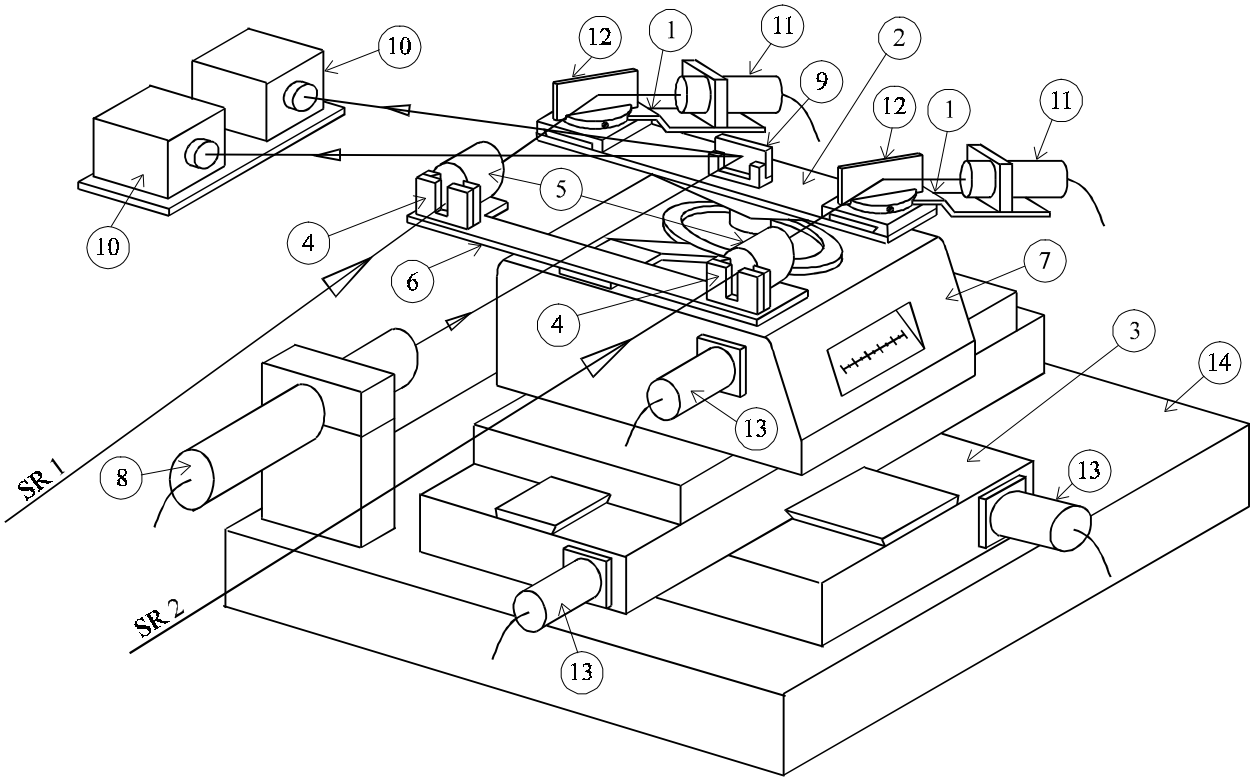

Fig. 3. The layout of the facility for absolute energy measurement.

3). These chambers to be connected in the differential mode permits to measure a flux difference of two swaths with the accuracy of 10^{-5} in one sec which cause the angular error of $\delta\varphi_3 = 5 \times 10^{7}$ rad.

4.3 The rocking angle measurement

A measuring display of a standard one-axis θ-2θ goniometer GUR-5 has an accuracy of 16 arc sec. The better accuracy can be reached using laser beam reflection by a mirror installed on a shaft of the platform. A pair of CCD cameras having a resolution of 20 μm installed at a distance of 10 m from the reflecting mirror will read the rocking angle with an accuracy better than 3×10^{-6} rad. This is the largest source of systematic error limiting the total accuracy of the bending angle measurement. For the bend angle of 8.17×10^{-2} rad this total accuracy is equal to 5×10^{-5} and the accuracy of absolute energy determination is mainly limited by the accuracy of the magnetic field mapping in the main dipoles, i.e., about 10^{-4}.

The layout of the facility is presented in Figure 3. Here (1) is K-edge absorption spectrometers, (2) the platform for spectrometers, (3) the microscopic table, (4) the input slits, (5) the ionization chambers, (6) the platform for slits, (7) the goniometer GUR-5, (8) the laser, (9) the reflecting mirror, (10) the CCD camera, (11) the detector, (12) the crystal, (13) the step motor and (14) the table.

The spectrometers with the slit system has been tested using conventional x-ray source as well the instrumentation for precision angular and linear displacement. According to experimental results the beam mean energy have to be measured with an accuracy better than 10^{-4} in the energy range between 400 MeV and 4.0 GeV for a CEBAF beam intensity of 10 μA and a Yerevan Electron Synchrotron intensity of about 10 mA.

5. REFERENCES

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