ELSEVIER

Nuclear Instruments and Methods in Physics Research A 448 (2000) 76–80

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.nl/locate/nima

Reflection of photons and azimuthal distribution of photoelectrons in a cylindrical beam pipe

V.V. Anashin[a], O.B. Malyshev[a], N.V. Fedorov[a,*], V.P. Nazmov[a], B.G. Goldenberg[a], I.R. Collins[b], O. Gröbner[b]

[a]*Budker Institute of Nuclear Physics, SB RAS, Loverentyev Prospect 11, 630090 Novosibirsk, Russia*
[b]*CERN, CH-1211 Geneva 23, Switzerland*

Abstract

In a cryogenic proton accelerator, such as the LHC, the creation of an electron cloud and generated heat loads resulting from electron bombardment are strongly dependent on the azimuthal distribution of created photoelectrons. In this context, photon reflection and photoelectron yield measurements have been performed using a beam line on the VEPP-2M storage ring. Six electrodes, covering the complete vacuum chamber perimeter, were mounted such that they could be suitably biased, and while one electrode was irradiated with synchrotron radiation the resulting electron current of all the others could be measured. A detailed description of the experimental apparatus and the results of the measurements of photon reflection and the azimuthal distribution of generated photoelectrons are presented. © 2000 Published by Elsevier Science B.V. All rights reserved.

PACS: 07.30.K; 84.47

Keywords: LHC; VEPP-2M; SR; Photon reflection; Photoelectron; Beam pipe; Strips

1. Introduction

Photon stimulated neutral gas desorption is a dominant effect for the design of vacuum systems exposed to synchrotron radiation (SR). It is generally accepted that neutral gas desorption is a two-step process where the incident photons excite photoelectrons which, in turn, excite bound molecules in the near-surface region causing these to be released from the surface. Electrons which escape the surface can contribute further to the gas desorption process when they return to the vacuum chamber. In the context of the design of the Large Hadron Collider (LHC) vacuum system it has been shown that the azimuthal distribution of photoelectrons in the vacuum chamber is a very important parameter, not only for gas desorption and additional heat loads, but also towards the creation of an electron cloud.

2. Experimental

The experiments were performed on the VEPP2-M electron storage ring at the Institute of

* Corresponding author. Tel.: + 7-3832-394202; fax: + 7-3832-342163.

E-mail address: nfedorov@inp.nsk.su (N.V. Fedorov).

PII: S0168-9002(99)00747-0

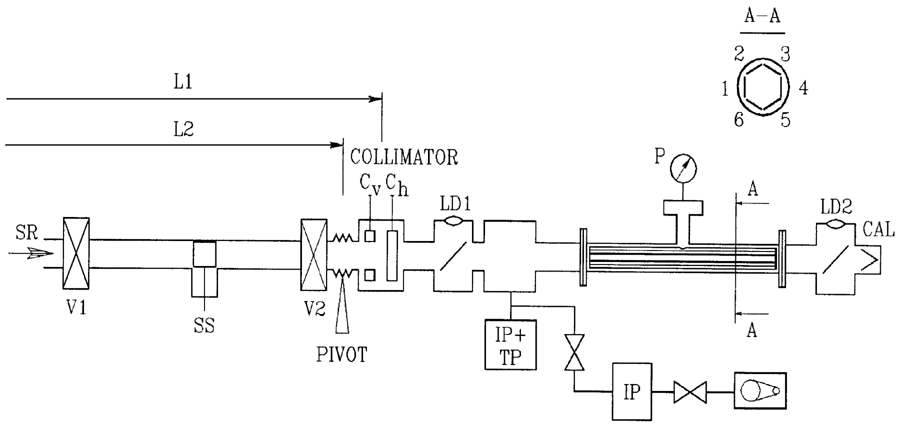

Fig. 1. The experimental set-up showing the cross-section A–A of the test chamber with 6 strip-electrodes. $L1 = 1280$ mm, $L2 = 860$ mm.

Nuclear Physics in Novosibirsk, Russia [1]. The experimental set-up, installed at the end of the SR beam line, shown in Fig. 1, was positioned at a distance of about 1 m from the source point of the SR where the effect of the vertical collimation on the photon flux is negligible. Here (SS) indicates a radiation safety shutter to interrupt the photon beam determined by a set of horizontal (C_h) and vertical (C_v) collimators on entering the experimental system. The position of the photon beam with respect to the experimental system could be checked with two luminescent screens, (LD1) and (LD2). At the exit of the test system, a calorimeter (CAL) was installed to monitor the SR beam. This calorimeter was designed in such a way that it could either measure the total SR power or the total photon flux derived from the photoelectron current produced on the calorimeter. For this measurement the calorimeter was electrically biased with respect to the test chamber. Additional elements shown in Fig. 1 are the two vacuum valves (V1) and (V2), the pumping system consisting of ion pumps (IP) and the titanium sublimation pump (TP) providing a combined pumping speed of about 1000 l/s for nitrogen, and, finally, the vacuum gauge (P) used for pressure measurements.

The experimental chamber designed for this study consisted of a 34 cm long and a 55 mm internal diameter beam pipe. Inside this tube, six strips, each 2 cm wide and 30 cm long were configured such that they formed a hexagonal shape covering the complete perimeter of the beam pipe. The whole experimental system could be either aligned straight or inclined at a given angle with respect to the axis of the photon beam. In the straight position, the photon beam traversed the test system and was incident on the end calorimeter, while in the inclined position, the photon beam was incident at an angle of typically 20 mrad along the electrode strip 1, see the inset drawing of the section A–A in Fig. 1. In the latter case, only reflected/scattered photons were able to reach the calorimeter.

During a typical measurement, the SR beam was incident on strip 1. The remaining strips received only scattered and reflected photons. Applying a negative bias in turn to each of the six strips while maintaining all the others at the common ground potential, the photoelectron current produced by photons on the corresponding strip was measured. A negative bias of less than 40 V was required to obtain a constant, saturated current signal. An alternative method used was to keep one strip at ground potential and to bias all others at a positive voltage with respect to ground. In this way the sum of the currents measured on all positive strips can be attributed to the photoelectrons originating from the grounded strip. Assuming that the average photoelectric yield for the direct incident photons and for the reflected, scattered photons are not too different, it is possible to derive from the measured azimuthal distribution of the photoelectron signal the azimuthal distribution of the photons. In the following sections, the data are presented in the form of the ratio I_i/I_Σ. A specially designed control unit was used to apply the required bias and to measure photoelectron currents from the array of strip electrodes.

3. Sample preparation

The sample materials used for this study have been stainless steel in the as-received state, i.e. rolled sheet material without any particular machining and surface treatment and a 0.05 mm high purity copper layer, co-laminated onto a stainless steel. These samples may be considered as being representative for either conventional stainless steel vacuum chambers or for the proposed material for the LHC beam screen, respectively [2]. The co-laminated copper samples have been studied firstly in their as-received state and subsequently after strong oxidation in air. This final surface treatment is a candidate procedure for lowering the photon reflectivity and, in addition, for achieving a low secondary electron yield for the LHC beam screen [3]. The controlled oxidation was achieved by heating the samples under vacuum to 300°C and exposing them for 5 min to air at atmospheric pressure. As a result of this procedure, the initially very bright and shiny copper surface turned dim.

4. Results

4.1. Photon reflection

The forward scattered reflection of SR was derived by comparing the two measurements when the photons are either directly incident on the calorimeter or after reflection from strip 1. This measurement was performed by rotating the experimental set-up around the pivot point to the chosen grazing angle of incidence of 20 mrad. Since the calorimeter was designed to measure power as well as photoelectron current, the forward scattered reflectivity results given in Table 1 summarise both measurements. The SR is a continuous spectrum, characterised by its critical energy ε_c, where the photon flux is dominated by the lower energy part and the power by the higher energy part. A comparison of the two different measurements provides interesting information about the energy dependence of these two effects. It should be noted that the sensitivity of the calorimeter for the power measurement sets a lower limit for the reflectivity of roughly 1%.

Table 1
Forward scattered reflectivity at 20 mrad grazing incidence on strip 1

Sample	Reflectivity (power) (%)	Reflectivity (photons) (%)
Stainless steel as-received	< 2	22
Cu co-laminated as-received	50	95
Cu co-laminated oxidised	20	65

The critical energy of the SR was not the same for all measurements but varied from about 245 eV for stainless steel and for the as-received co-laminated copper sample to 205 and 113 eV for the oxidised copper sample. In spite of this variation, no significant spread in the forward scattered reflectivity values was observed.

4.2. Azimuthal distribution

The azimuthal distribution of the photons and thus of the photoelectrons generated on the individual strips can be expressed in terms of the ratio I_i/I_Σ. The results are summarised in Table 2 where it can be seen that the dominant region of photoelectron production is located in the region where the primary photons strike strip 1.

The values in Table 2 have been derived without accounting for the fact that a varying fraction of the incident photons are reflected and, therefore, do not contribute to the measured photoelectron current in the set-up due to its limited length. In a more realistic case of an accelerator with a continuous long beam pipe, reflected photons will interact further downstream and produce photoelectrons there. To illustrate the importance of this effect one can see that for the oxidised copper sample, about 95% of the photoelectrons

Table 2
Azimuthal distribution of the photoelectron emission in percentage of the sum signal from all strips

Sample	ε_c (eV)	Strip 1	Strip 2	Strip 3	Strip 4	Strip 5	Strip 6
Stainless steel	243	74	2.5	5	11	5	2.5
Cu bright	245	90	1.8	2	2	2	1.8
Cu oxidised	205–113	95	1	1	1.3	1	1

Table 3
Azimuthal distribution of the photoelectron emission in percentage of the sum signal from all strips and normalised to the fraction of absorbed photons

Sample	ε_c (eV)	Strip 1	Strip 2	Strip 3	Strip 4	Strip 5	Strip 6
Stainless steel	243	60	1.5	3.5	8.5	3.5	1.5
Bright Cu	245	4.5	0.1	0.1	0.1	0.1	0.1
Oxidised Cu	205–113	30	0.3	0.3	0.5	0.3	0.3

are produced on the strip 1 but, as can be seen from Table 1, 65% of the incident photons are reflected and would illuminate the beam pipe further downstream. Therefore, it is considered more appropriate to normalise the data to the absorbed part of the incident photon flux by multiplying all values by the factor $(1-R)$. Here R is the photon reflectivity listed in the last column of Table 1. The result is shown in Table 3 and these values can be compared more directly with the other measurements [4].

5. Conclusion

Most of the photoelectrons are created in the region of the primary impact, i.e. in the median plane of the beam pipe. To correctly interpret the data of this experiment, the fact that a large fraction of the photons is nearly specularly reflected and hence falls on the calorimeter at the end of the test system cannot be ignored. In a practical situation, such reflected photons can propagate along the beam pipe and will be absorbed at some distant location. Depending on the respective scattering/reflection angle these photons may ultimately illuminate the whole perimeter of the beam pipe. This effect will, therefore, tend to increase the production of electrons on the indirectly illuminated strips (2–6).

The forward scattered reflectivity as measured by the deposited power and by the number of photons show significantly different results suggesting that predominantly the low-energy photons are reflected. Indeed, at 20 mrad grazing angle of incidence, the forward scattered reflectivity for a smooth copper surface [5] would be close to unity for photon energies up to several hundred eV. With respect to the electron-cloud effect in the LHC [6] a low reflectivity is desirable since it will limit the photoelectron production to the region of the primary impact of the photons in the horizontal plane where electrons are effectively suppressed by the strong vertical magnetic field. From this point of view, the oxidised copper appears to be the most promising surface.

References

[1] V.V. Anashin, N.A. Gorbunova, I.A. Koop, V.P. Nazmov, V.N. Osipov, V.F. Pindyurin, Nucl. Instr. and Meth. A 359 (1995) 437.
[2] P. Cruikshank et al., Mechanical Design Aspects of the LHC beam screen, LHC Project Report 128 and PAC'97, Vancouver, 12–16 May, 1997.
[3] I. Bojko, J.-L. Dorier, N. Hilleret, Ch. Scheuerlein, Lowering the secondary electron yield of technical copper surfaces by strong oxidation. LHC Vacuum Technical Note 97-19, June 1997.

[4] V. Baglin, I.R. Collins, O. Gröbner, Photoelectron yield and photon reflectivity from candidate LHC vacuum chamber materials with implications to the vacuum chamber design, EPAC'98, Stockholm, June 1998.
[5] B.L. Henke, E.M. Gullikson, J.C. Davis, Atom. Data Nucl. Data Tables 54 (1993) 181.
[6] V. Baglin, O. Bruning, R. Calder, F. Caspers, I.R. Collins, O. Gröbner, N. Hilleret, J.-M. Laurent, M. Morvillo, M. Pivi, F. Ruggiero, Beam-induced electron cloud in the LHC and possible remedies, EPAC'98, June 1998.