STUDY OF SR-MONITOR HEATING FROM E^+E^-- BEAMS AT DESY.

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Abstract

The thermal calculations are presented on the monitors of the synchrotron radiation (SR), generated by e^+e^- – beams in HERA and DORIS. For monitor electrodes heated by SR the case of cooling due to the heat radiation and heat conductivity is considered. The temperature distribution on the electrode plates was obtained for various monitor parameters and irradiation modes. After this calculation study a first prototypes of the synchrotron radiation monitor (SRM) without force heat removing systems has created and installed at DORIS and HERA. The initial experience with these SRM is reported.

INTRODUCTION

SRM was being designed in agreement between IHEP and DESY and intended for registration of the SR beam profile, generated in magneto-optical elements of accelerators. For HERA these elements placed before an interaction point of the e-p beams. Presence of correlation of SR and electron beam configurations allows by such method remotely to control the e-beams. The SR beam is extracted into the external beam pipe, where SRM is placed on a distance of 24 meters from IP. At this point the SR beam has horizontal and vertical sizes of 5 cm and 0.5 cm, respectively. And in DORIS these sizes are of 5 and 0.1 cm. The energy limits of the SR photons in HERA are of 10-200 KeV. The SR beam power reaches to 26 kW at the nominal energy and current of the e-beam (30 GeV, 58 mA for HERA and 4.5 GeV, 100 mA for DORIS). Simultaneously with above conditions the main requirements to SRM were:

- measuring field exceeding the SR beam size,
- wide amplitude range (10^6),
- possibility of operation in superhigh vacuum (10^{11} Torr),
- cooling without using of coolant.

According to these requirements in IHEP the multi-channel SRM using the x-ray photoemission effect is designed.

Fig. 1 schematically shows the SRM head, consisting of assemble of plane-parallel electrodes: 5 of them are the signal cathodes and other 6 are the screen anodes. The cathode bottom edges are attached to the isolating cartridges, and the anodes are mounted on common base. Electrodes are made of tungsten because of its high photoemission capability and melting temperature. The SR horizontal profile is being measured by the stationary distributed cathodes. The vertical profile is being measured by the scanning of the SR beam vertically moving the SRM head. The main mechanism of the electrode cooling is a heat radiation. So the ability of the electrodes to tolerate an extreme thermal load is very important.

Numerical calculations results of the electrode heating are represented below depending on a variation of the SRM parameters and the irradiation mode.

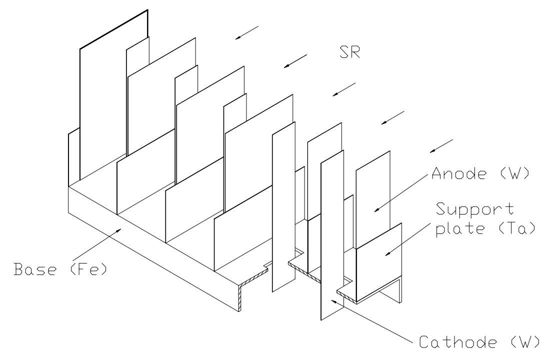

Figure 1: The SRM head

CALCULATION METHOD

The calculations were performed for the SRM model consists of 2 anodes and 1 cathode (see Fig. 2). The parameters d, D and α were changed at the calculation.

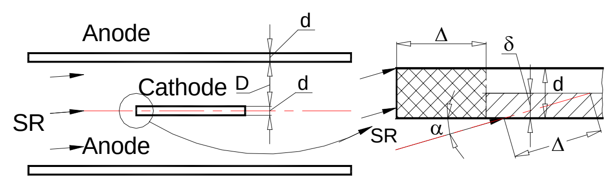

Figure 2: The calculation model of SRM.

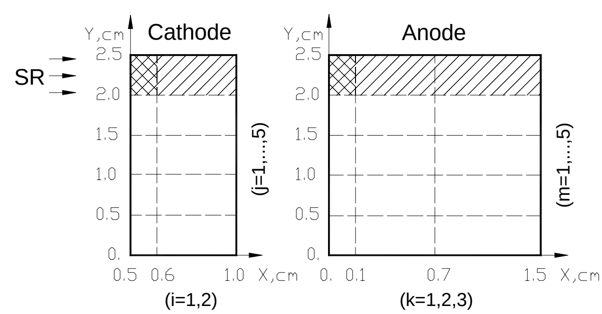

Figure 3: The zones of a cathode and an anode.

Fig. 3 shows the lateral sizes of a cathode and an anode, which were not changed. The electrode temperature was calculated based on the heat radiation of the electrodes and the heat conductivity of the electrode support. The case of the electrode heating at the SR transmission via the upper electrode edges was considered. In this case the

electrode surfaces of will be significantly anisothermic. That's why a zonal method of a heat radiation exchange [1] was used. The electrode surfaces were separated into several zones (see Fig. 3) having different temperatures.
Double hatching shows zones in which energy deposition (q_{max}^{SR}) does not depend on an angle α. Unary hatching selects zones in which energy deposition (q^{SR}) depend on α. Dependence q^{SR} and α (see Fig. 2) is defined by pass depth of SR (Δ) and of an electrode thickness (d): $q^{SR}= q_{max}^{SR}\cdot\Delta/d\cdot\sin\alpha$. Value Δ was accepted equal 1 mm. As d << Δ this formula is applicable for corners $\alpha \le d/\Delta$.

At first the system of lineal equations describing a heat radiation exchange between zones of the cathode and the anode was solved. The unknown values were own q^S and effective q^E radiation of zones, and the given values were energy deposition q^{SR} and geometrical zone parameters. It was assumed, that between zones there is a local thermodynamic equilibrium, law Lambert [1] is fulfilled and a coefficient of blackness is equal to an absorption coefficient. The energy balance for each zone is described by 2 equations. So, for cathode zone of these equations are:

$$q_{ij}^{E} - \sum_{m}\sum_{k}\varphi_{km\to ij}\cdot q_{km}^{E} + q_{ij}^{S} = q_{ij}^{SR}$$

$$-q_{ij}^{e} + \sum_{m}\sum_{k}\cdot\left(1-\varepsilon_{ij}\right)\varphi_{km\to ij}\, q_{km}^{E} = 0$$

where q_{ij}^E and q_{ij}^S - equivalent and own radiations of the cathode zone, q_{km}^E - equivalent radiation of the anode zones, q_{ij}^{SR} – SR energy deposition, $\varphi_{km\to ij}$ – angular factor for the irradiation from the anode zones {km} into the cathode zone {ij}, ε_{ij} – coefficient of blackness.

Taking into account symmetric of the SRM model (see Fig. 2), the system with 50 equations was formed. This system was solved by Gauss-Jordan method of exclusion [2]. With this purpose program SYHEAT was designed. The program allows to perform changes the SRM parameters and the operating modes. Using the calculated values of the own zone radiations, the zone temperatures were computed with Stefan-Boltzmann formula [1]:

$$\frac{q^{S}}{F} = \varepsilon\cdot C_{0}\cdot\left\{\left(\frac{T}{100}\right)^{4}\cdot\left(\frac{T_B}{100}\right)^{4}\right\}$$

where F – a zone square, T – absolute zone temperature, T_B = 300K – beam pipe temperature, ε – coefficient of blackness, C_o = 5.6703×10-4 W/cm^{2}K^4 – radiation coefficient of absolutely black body.

The influence of electrode heat conductivity was performed iterationly using a correction to the SR energy deposition of the zones. At this correction the heat conductivity of an electrode material and a support contact and also a temperature difference between the neighbor zones was taken into account. The temperature difference came out from the preceding iteration.

CALCULATION

First important interest was to calculate the dependence of the maximum electrode temperature from the SR energy deposition density for two basic irradiation modes: on all electrode width (axis X) and on a narrow edge strip of 1 mm. The first mode ("plane") is realized at the SR incidence angle $\alpha \ge d/\Delta$, and the second mode ("edge") – at α=0. In the first mode the greater current of photoelectrons are emitted, but in the second – is essentially reduced a total energy deposition in electrodes.

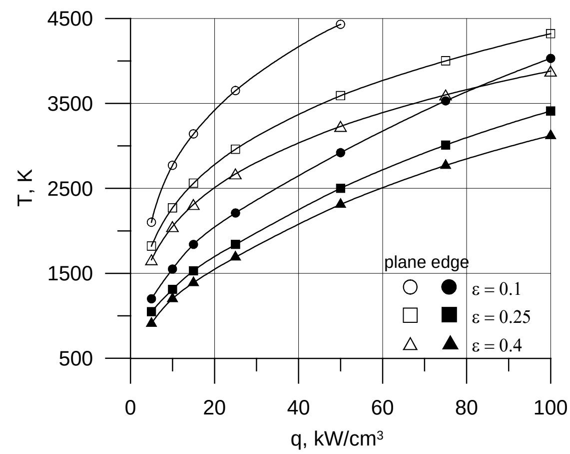

Figure 4: The maximum temperature of the cathode as function of the energy deposition density.

Fig. 4 gives the dependences of the cathode maximum temperatures for both irradiation modes at various coefficients of blackness (0.1, 0.25 and 0.4). The anode temperature is lower than cathode temperature on 500-700 K, because anode has better cooling caused by the heat radiation and the support heat conductivity. At these calculations the electrode thickness is accepted equal 50 μm, and a distance of 5.5 mm between the electrodes. These values are selected from the reasons of a mechanical stability and on the base of corresponding thermal calculations.

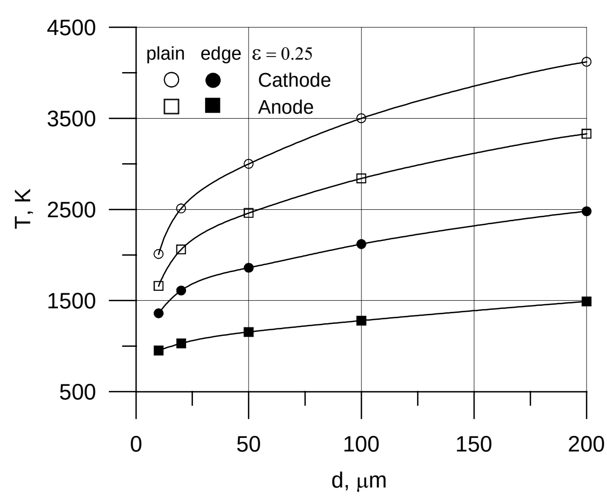

Figure 5: The maximum temperature of the cathode and anode as function the electrode thickness.

Dependence of maximum temperature of the cathode and the anode on their thickness for coefficient of blackness 0.25 and energy deposition density 25 kW/cm3 is shown on Fig. 5. Taking into account, that the coefficient of blackness can be lower and the energy deposition density can be higher than the values accepted in the calculations, usage of an electrode with the thickness greater 50 microns is unsuitable. The electrode spacing decreasing will lead to an abrupt growth of the electrode temperature, and at the increase – the temperature practically remains to a constant. The SRM operating mode was chosen on the base of the following factors:

- SR energy deposition density in a tungsten reaches of 15-30 kW/cm3,
- tungsten strength properties become significantly worth under temperatures greater then 2500 K [3],
- radiation destruction of the electrodes takes place under the long-run operation.

On the basis of the thermal calculation results and of these factors follows, that the operating mode "edge" is the most acceptable one. However, there are difficulties in the realization of such mode caused by the SR angular dispersion and compilation inaccuracy. So it’s helpful to estimate the dependence of the electrode temperature from the SR incidence angle. The results of corresponding calculations for the temperatures in upper and bottom cathode zones for the coefficient of blackness of 0.1 and 0.25 are represented in the Fig. 6.

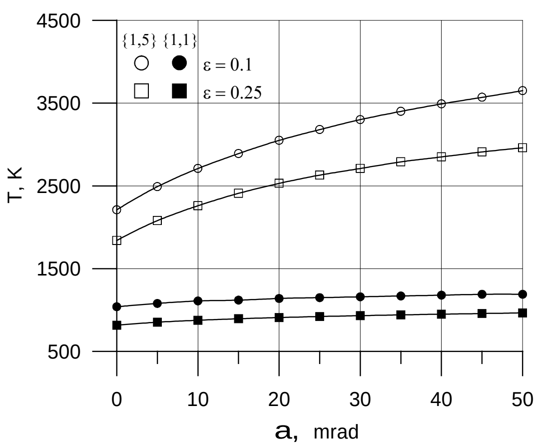

Figure 6: Dependence of the temperatures in upper and bottom cathode zones from the SR incidence angle.

TEST OF SRM PROTOTYPE

The SRM prototype free from forced cooling was designed and manufactured on the base of the thermal calculations. The part of the drive device consisting of the SRM head with the electric and fastening elements is shown in Fig. 7. In the operation mode 2 heads are moved to upper and bottom edges of a beam pipe. Beam scanning occurs vertically. The SRM electrodes are made of a rolling tungsten foil of 50 μm thickness. Temperature sensors are arranged in the cathode bottoms. SRM testing was performed in DORIS under the different intensity values and the irradiation durations. The performed trials demonstrate, what the given SRM construction allows constantly to monitoring of the SR beam within a year. The photo of the SRM head represented in the Fig. 7 was taken after one-year service at HERA. The thermal damages of the electrodes are not seen.

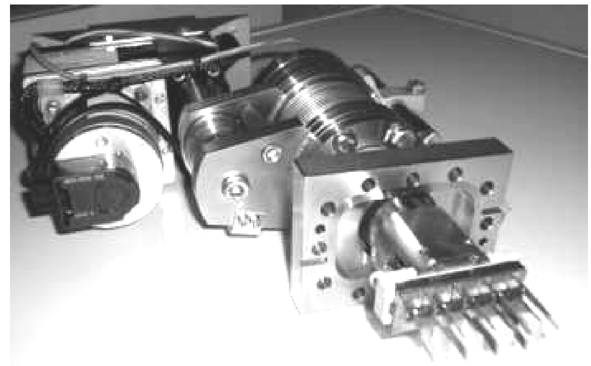

Figure 7: The SRM prototype for HERA.

The temperature was measured under the 126-118 mA e-beam current was performed in DORIS. The experiment results and the calculated estimations are given in table 1. The interval of the calculated temperature is defined by the difference of about 10 times of possible values of the coefficient of blackness and the contact thermal resistance at the cathode support.

Table 1: The experiment and calculated temperature at the cathode bottoms.

№ cathode	T_{exper}, K	T_{calcul}, K
1	560	550-650
2	580	
3	570	
4	550	
5	570	

CONCLUSION

The calculation study and the SRM prototype testing provided an opportunity to implement the construction of a long-run monitor free from forced cooling of the electrodes. As it follows from the calculations the maximal energy deposition can be increased due to decreasing of the electrode thickness and the use of the coefficient of blackness larger then before. It will allow the use such type monitors with more intensive the SR beams.

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REFERENCES

[1]P. Isachenko, V. A. Osipov, A. S. Sukomel. Teploperedacha. M.: Energoizdat, 1981 (Russian).
[2]T. Shup. Applied numerical methods in physics and engineering. M: the Higher school, 1990.
[3]W. Espe. Werkstoffkunde der Hochvakuumtechnik. VEB Deutscher Vertag der Wissenschaften, Berlin.