Radiological studies during the conditioning of the RF cavity for the ALBA Storage Ring

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Abstract

ALBA is a 3 GeV, 400 mA, 3rd generation Synchrotron Light Source that is in the construction phase in Cerdanyola, Spain. The Storage Ring (SR) will have 6 RF single cell cavities to maintain the beam energy at 3 GeV. The first cavity was delivered in 2007 and it was conditioned during 2008. The conditioning was done inside a bunker aiming to guarantee the dose rate level below 0.5 μSv/h at any work place outside this bunker. We present the radiation measurements performed during this conditioning stage. The measurements were done using TLD dosimetry, online gamma monitor, portable detector and gamma spectrometer.

1. Introduction

This paper describes the first radiation measurements performed during the conditioning stage of one of the six ALBA SR cavities. Radiation measurements outside the shielding have been done to verify that the shielding reduces the dose rate below 0.5 μSv/h. Dose rate and spectrum measurements inside the shielded area have been done to study the production of radiation as a function of the RF power.

1.1. ALBA RF system

The ALBA SR RF System provides 3.6 MV of accelerating voltage and restore up to 540 kW of power to the electron beam [1]. This will be done by 6 High Order Mode damped cavities tuned at 500 MHz, designed at BESSY and known as the EU cavity (see Figure 1). Each cavity will be feed by two RF amplifiers based on an Inductive Output Tube (IOT) that delivers up to 80 kW each one. The six cavities are grouped in three pairs along the SR. In Fig.2 a picture of one of the three RF plants partially installed at the ALBA Service Area is shown.

Fig.1 - ALBA SR cavity inside the bunker.

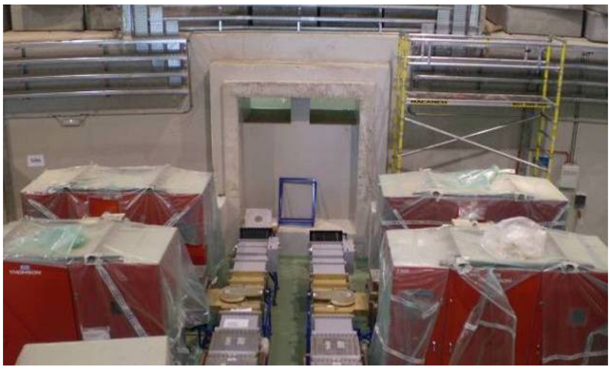

Fig.2 - ALBA SR RF plant. The four IOTs are in the four red cabinets. The two apertures of the tunnel wall can be observed because the RF labyrinth cover is removed for the installation of the waveguides (not finished yet).

1.2. The RF bunker

For the conditioning of the RF cavities, the six of the SR and the one of the Booster, a dedicated bunker was built aiming to guarantee a free access outside it (0.5 μSv/h). Like in the RF system at the ALBA synchrotron, the IOT is placed outside the bunker, and the cavity inside. A waveguide drives the power from the IOT to the cavity entering the bunker through the upper part (see Fig.3). The bunker has no roof. The cavity is oriented in a way that the beam axis crosses the measurement point A and the wall of measurement point C perpendicularly.

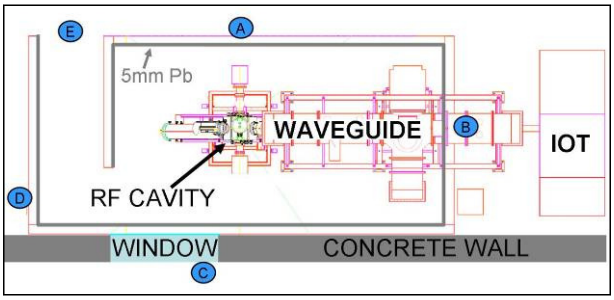

Fig.3 - Top view of the RF bunker. The measurement points outside the bunker are indicated in the blue circles.

In order to absorb the radiation generated in the cavities, the brick walls are covered with a lead foil of 5 mm. The calculations to determine this thickness are based on experimental results of dose rates outside the cavity as a function of the power [2]. In this study, the cavity has the same design as the ALBA Booster RF cavity, also commissioned in this bunker.

The first radiation measurements with the SR cavities (see later), revealed the need of a RF bunker shielding reinforcement. As a result, the wall side of measurement point A was reinforced with 30 cm thickness heavy concrete blocks of 3.8 g/cm^3 (see Fig.4). In the opposite side, a lead screen of 5 cm was installed inside the bunker between the cavity and the wall of measurement point C (see Fig.4).

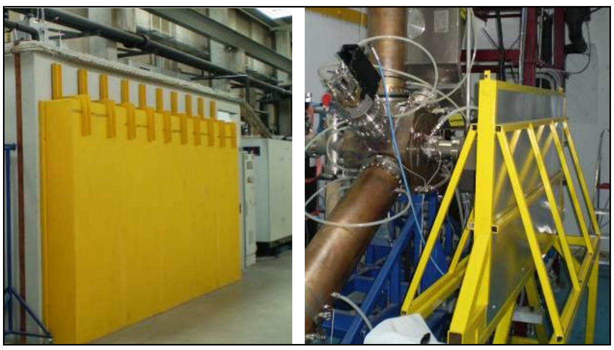

Fig.4 - Heavy concrete shielding reinforcement at measurement point A (left) and lead shielding reinforcement between the cavity and measurement point C (right).

A Personal Safety System (PSS) is installed in the RF bunker. It prevents anyone to be in the bunker while the cavity is receiving power. This system, based in PLC technology, is composed by search and emergency buttons, a door locker and switch, light panels, beepers, access cards and a safety PLC. The PSS components are certified as SIL3 security level [3].

2. Measurements

During the conditioning phase of the SR cavity, measurements were done using TLD dosimetry, portable detectors, an online gamma monitor and a gamma spectrometer. The measurements are divided in two categories: measurements outside the bunker and measurements inside the bunker.

2.1. Dose rates outside the bunker

The measurements outside the bunker aim to verify that the dose rates at public zones are below 0.5 μSv/h. The commissioning of the RF system started with the IOT startup. The dose rate measured with portable detectors outside the IOT cabinet with the door closed was 0 μSv/h. Inside the cabinet, the dose rate on surface of the IOT raised up to 100 μSv/h at 80 kW; the maximum power. Thus, the access to the cabinet is restricted and controlled with a key. The portable detectors used for the measurements are gas chambers suitable for X-ray energies higher than 25 keV.

During the first tests of the SR cavity the maximum power (80 kW) could be achieved with a duty cycle of 20 ms at 10 Hz (20% of average power). The dose and dose rates were measured by means of TLDs and portable detectors. In Table-1 the survey measurements with portable detectors are shown. The dose rates were much higher in the beam axis direction; the direction where the electric field is expected to be maximum. In order to guarantee that the dose rate outside the bunker is below 0.5 μSv/h, at a duty cycle of 100% a shielding reinforcement was required at the walls that intercept the beam axis; the ones of measurement point A and C.

	Dose rate (μSv/h) @ point				
	A	B	C	D	E
Without shielding reinforcement	14-25	0.3	3.5	0.0	0.5
With shielding reinforcement	0.07	0.3	0.08	0.0	0.5

Table 1 - Measured dose rates outside the RF cavity bunker with and without shielding reinforcement with portable detectors. The measurements were done at 80kW RF power, 20% duty cycle, at beam height.

The required extra shielding was determined measuring the dose rates with a detector shielded with different materials and thicknesses. These measurements were done at a duty cycle of 20%. The results were extrapolated to guarantee dose rates outside the bunker below 0.5 μSv/h at a 100% duty cycle. The wall of measurement point A was reinforced with 30 cm thickness heavy concrete blocks of 3.8 g/cm^3. In the other direction, a lead screen of 5 cm was installed between the cavity and the measurement point C. The measurements were repeated with 20% duty cycle after the installation of the shielding reinforcement (see Table-1). The dose rates of points A and C decreased below the 0.1 μSv/h limit; what corresponds to 0.5 μSv/h for a 100% duty cycle.

The bunker has no roof. The radiation doses were measured at a RF power of 80 kW with a duty cycle of 20%. The dose rate above point A on top of the wall (3 m height) was 70 μSv/h. At 3 m height the dose rates were 0.8 μSv/h, 0.6 μSv/h and 0.4 μSv/h at one, two and four meters away the bunker wall. Thus, a special permission is required to work at height near the bunker while the RF is on.

2.2. Dose rates inside the bunker

Three types of measurements were done inside the bunker, TLD dosimetry, online dose rate monitoring and X-ray spectroscopy. These measurements aim to study the generation of radiation by the cavity and relate it with the RF power. The production of dark currents by field emission in radiofrequency (RF) cavities is well known [4]. These electrons are accelerated in the cavities and can impact the inner walls generating Bremsstrahlung radiation. These X-rays can leave the cavity generating a radiation environment around it

[5]. The production of the dark currents, and therefore the X-rays, is much more important throughout the first runs of the cavity, the conditioning period.

The accumulated dose at the outer surface of the cavity was measured with TLDs at 80 kW and 20% duty cycle during one hour of operation. The dose rate at the RF surfaces that intercepts the beam axis (facing the measurement points A and C) was ~14 mSv/h. The dose rate at the RF surfaces perpendicular to the beam axis (facing the measurement points B and D) was ~3 mSv/h. Also at 80 kW and 20% duty cycle, the dose rates were measured at the inner surfaces of the bunker walls with TLDs. Next to points A, B, C and D, the dose rates inside the bunker were 227 µSv/h, 6 µSv/h, 174 µSv/h and 26 µSv/h, in that order. The dose rates were much higher in the direction of the beam axis. This direction is the one that maximizes the electric field and therefore the direction which more electrons can be extracted through field emission and the dark current electrons can be more accelerated. These dose rates were calculated from the TLDs accumulated dose and the RF cavity operation hours.

A radiation monitor was installed inside the bunker next to measurement point A to acquire the photon dose rate online (see Fig.1). This let us correlate the radiation dose with the RF power in the cavity; also measured online. In Fig.5 the dose rate and the RF power are shown during one cycle; increase the RF power from 0 kW up to 80 kW and decrease it again to 0 kW. The radiation generated by the RF cavity is measured for RF powers lager than 25 kW.

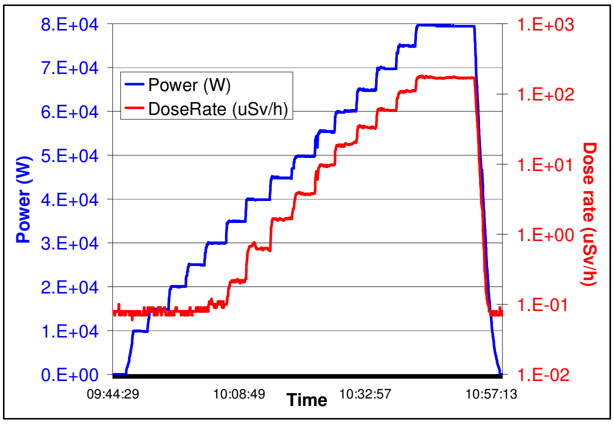

Fig.5 - RF power and photons dose rate inside the bunker during one cycle.

In Fig.6, the dose rate is plotted as a function of the RF power for different cycles for different days. The dose rate decreased as the cavity was more conditioned. The dose rate corresponding to April 29th was higher when decreasing the RF power. The explanation of this effect is still under discussion.

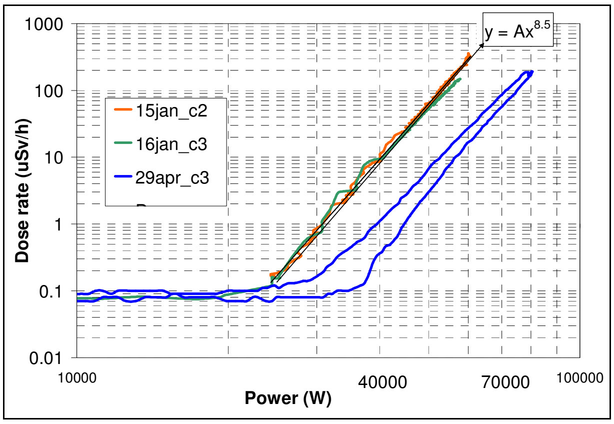

Fig.6 - Photons dose rate as a function of the RF power during three cycles of different days. The April 29th cycle dose rate is higher during the RF decrease.

The January 15th data is fitted to a power function (see Fig.6). This dependence is described in other works, where the power constant is 10.5 [5] or 9.6 [4]; while in our case is 8.5. The difference in the exponent could be probably attributable to the characteristics of the different cavities.

The X-ray spectrum was measured inside the bunker. The spectrum was measured during two minutes for different RF powers from 45 kW to 80 kW in steps of 5 kW (see Fig.7). The maximum energy detected by the spectrometer increased when increasing the RF power. This is because the electric field inside the cavity increases when increasing the RF power. The maximum energy of the Bremsstrahlung radiation that can be generated in the cavity is the maximum energy of the dark current electrons; which is proportional to the electric field in the cavity. As the RF power is proportional to the square of the electric field in the cavity, the maximum X-ray energy that can be generated in the cavity is proportional to the square root of the RF power. In Fig.8, the maximum energy of the X-rays spectrum is plotted as a function of the square root of the RF power. The data is fitted to a linear function showing a good agreement (R^2=0.990). During the whole conditioning period, the maximum X-ray energy measured with the spectrometer was 800 keV; at the beginning of the conditioning period.

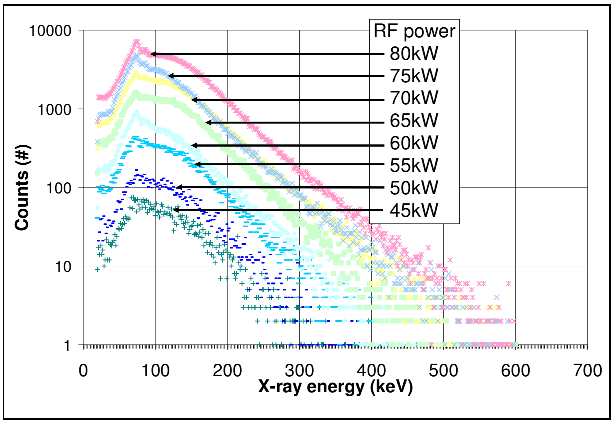

Fig.7 - X-ray spectrums at a different RF power from 45kW to 80kW in steps of 5kW. The spectrums were measured at 1m from the cavity surface inside the bunker (near measurement point A).

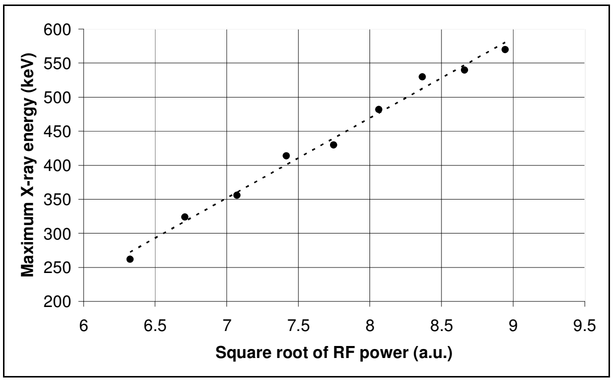

Fig.8 - Maximum energy of the x-ray spectrum as a function of the square root of RF power.

3. Simulations

A Monte-Carlo simulation of the cavity is done with the FLUKA code [6]. This simulation aims to estimate the current of electrons extracted from field emission and accelerated inside the cavity. The gamma dose per primary electron hitting the inner part of the cavity is simulated inside and outside the bunker. For this simulation two simplifications are taken: consider the cavity as a 15 mm thick walls copper cylinder and consider a 800 keV monoenergetic dark current electron beam (see Fig.9). The first assumption is taken because it is not known where the electrons hit the cavity. Fifteen millimeters is the average surface thickness of the face where the electrons can impact. Secondly, 800 keV is the maximum X-ray energy measured with this cavity.

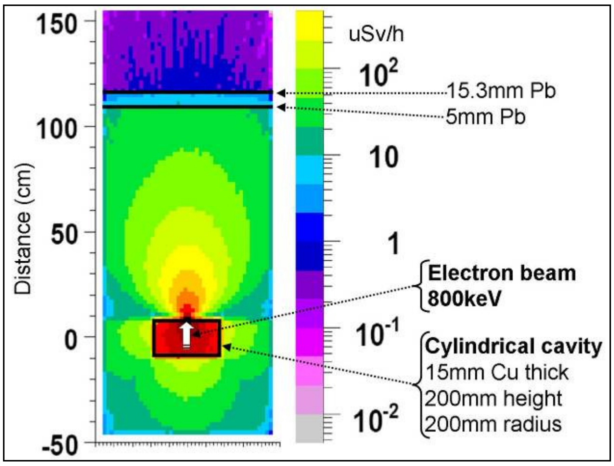

Fig.9 - RF cavity simulation layout and dose rates. The electron current has been scaled to fit the measured dose rates.

The electron current in the cavity is estimated matching the simulated pSv per primary electron after two lead foils ($2.5 \cdot 10^{-13}$ pSv/e and $3.4 \cdot 10^{-14}$ pSv/e) with the measured dose rate (14.3 μSv/h and 1.9 μSv/h). The first lead foil corresponds to the bunker wall shielding and the second one was added for the measurement. The heavy concrete reinforcement was not installed yet during this measurement. The obtained dark current is 2.5nA; what is in the range of the currents measured in other published works [4].

4. Conclusions

The radiation dose rate levels have been studied inside and outside the RF bunker during the conditioning period. The need of a shielding near these elements has been shown. Subsequent measurements have confirmed that the shielding reinforcement guarantees dose rate levels below 0.5 μSv/h outside the bunker. The power dependence of the radiation as a function of the RF power is studied monitoring the radiation inside the bunker. The measured dependence is in agreement with published studies. Also inside the bunker, the X-ray spectrum has been measured at different RF powers. A linear dependence between the maximum X-ray energy and the square root of RF power has been shown. This could be explained relating the maximum energy of the dark current electrons with the electric field in the cavity; which is proportional to the square root of RF power. Finally, Monte-Carlo simulation of the generated dose rate has been carried out. From this simulation, the dark current has been estimated.

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