BREMSSTRAHLUNG MEASUREMENTS AT THE ESRF

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Abstract

Increased bremmstrahlung radiation levels were observed around several ESRF beamlines, which had been equipped with new insertion device vacuum vessels with a reduced vertical aperture. In order to understand the origin of this increased radiation, detailed bremsstrahlung measurements have been carried out on several beamlines. This paper describes the results of these measurements. The measurements allowed the dose levels originating from the gas-bremsstrahlung component to be quantified. However, precise vertical profile measurements have clearly indicated the presence of a second bremsstrahlung component, due to a scraping effect of the electron beam at these reduced vertical apertures. It was shown that the latter component could easily be the predominant one in the radiation dose levels observed around the beamlines. The curing effect of changing the storage ring optics from a high β to a low β optics was clearly demonstrated.

1 INTRODUCTION

People working on the beamlines in the Experimental Hall of the ESRF are not considered as workers exposed to radiation. Therefore the shielding of the beamline hutches must guarantee dose rates below 2.5 μSv/h. In order to allow for a certain error in the dose measurements, as well as anticipating new legal dose limits (based on ICRP 60), our aim is not to exceed measured levels of 0.3 to 0.4 μSv/h.

The use of an X-ray shielding computer code, developed at the ESRF, as well as a by now well-established hutch construction standard, has resulted indeed in such low dose rates.

However, in 1995, increased radiation levels were measured around a number of beamlines, which had been equipped with new 5 metre long insertion device vessels, with a reduced vertical aperture (11 mm internal gap). This increased radiation, although still relatively low (a few μSv/h) presented a big problem in view of our general radiation protection policy.

This paper describes the origin of this radiation, as well as the solutions which were adopted to solve the problem.

2 SHIELDING REQUIREMENTS FOR ESRF BEAMLINES

Synchrotron beamline hutches must provide shielding against two distinct radiation sources: synchrotron radiation and bremsstrahlung. In the case of the ESRF the lateral shielding of these hutches will be determined by the synchrotron radiation. Indeed, the high power of the synchrotron sources (both insertion devices and bending magnets) and the high critical energies (up to several 10 keV) imply that a lot of scattered radiation is produced on the various optical elements. The bremsstrahlung radiation on the other hand, although highly penetrating, requires essentially shielding in the forward direction. Scattering at larger angles is due to multiple scattering of electrons and delta-ray production. These processes are much weaker than the Compton scattering of hard X-rays. Shielding against bremsstrahlung therefore essentially requires the addition of a typically 1 m^2 wide, 10 cm thick lead wall on the hutch back wall, centred around the 0º beam axis.

The spectrum below, measured with a Ge detector behind the side wall of a hutch, shows indeed a pure X-ray spectrum. One sees the primarily Compton scattered X-ray contribution, lower energy, multiple scattered X-rays (mainly in the shield wall) and the lead fluorescent rays.

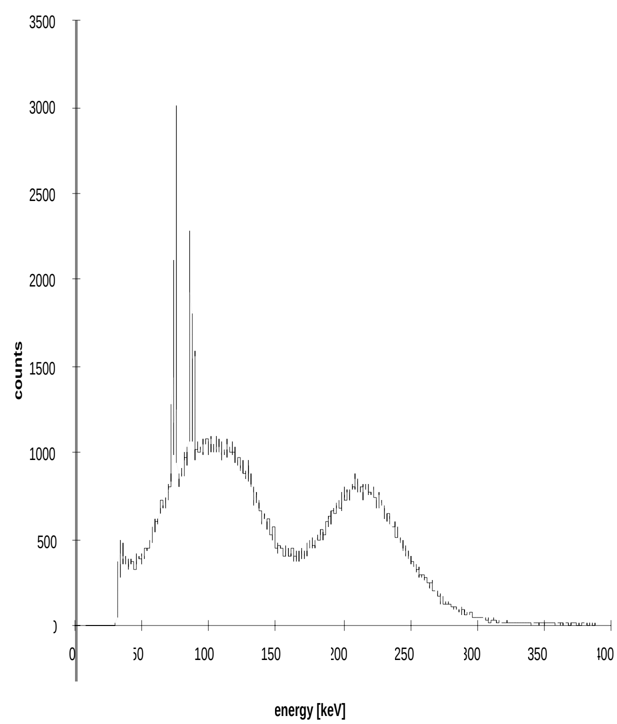

Figure 1: Example of a measured X-ray spectrum behind an optics hutch side wall.

When in 1995 new insertion device vacuum vessels, with smaller vertical aperture (11 mm internal gap) were installed, increased radiation levels outside the beamline hutches were measured (of the order of a few μSv/h). It turned out that this radiation, after an initial period needed for the vacuum conditioning of these new vessels, persisted only on insertion device beamlines, installed on high β straight sections. This radiation was clearly identified as bremsstrahlung. Indeed, spectra measured with a Ge detector showed the presence of high energy photons. As an example we show one of these spectra. The presence of 511 keV annihilation photons is a clear footprint of bremsstrahlung photons. It is clear that, because of the decreasing detector efficiency with increasing energies, the measured dose rates are mainly due to these high energies.

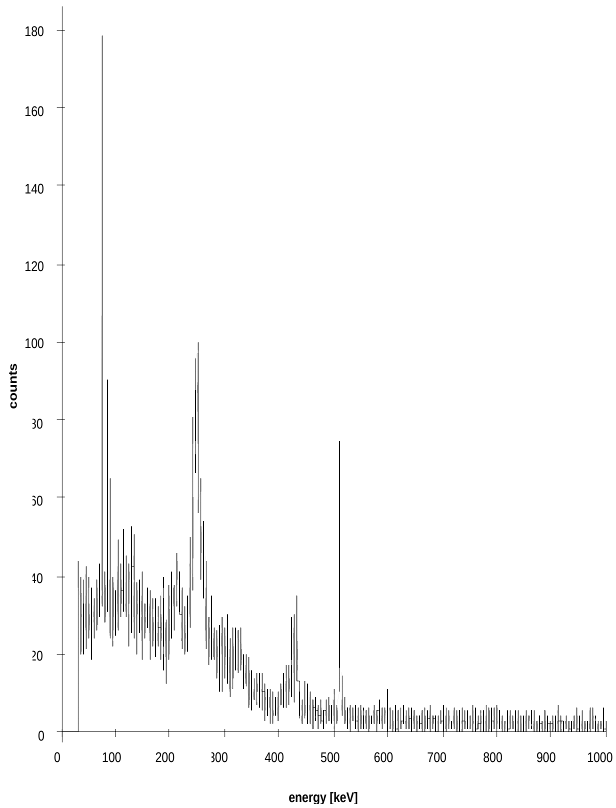

Figure 2: Example of a bremsstrahlung dominated spectrum, measured behind an optics hutch side wall.

3 BREMSSTRAHLUNG MEASUREMENTS

Initially some confusion existed about the origin of this radiation. Either it was gas bremsstrahlung, due to increased vacuum level inside the 5 metre long vessels (pumping is only foreseen at the two extremities of the vessel, and a higher gradient could not be excluded due to a reduced conductance) or the bremsstrahlung originated from a more direct interaction mechanism between the electrons and the reduced aperture ("scraping" effect).

Therefore, in order to identify the source of this increased radiation, more detailed measurements were carried out. Bremsstrahlung profiles were measured using a small ionisation chamber (0.6 cm^3 Farmer type chamber). This chamber was scanned vertically through the bremsstrahlung beam, behind a 3 cm thick lead wall. This lead wall eliminated possible scattered synchrotron radiation from the upstream and downstream dipole, and also provided sufficient dose build-up for the high energy radiation.

Several measurements were made. One measurement was carried out on a low β straight section, following the evolution of the bremsstrahlung during the vacuum conditioning of a newly installed 11 mm vessel. This measurement proved a normal behaviour, with a correct vacuum conditioning, and the bremsstrahlung intensities were completely proportional with the product of pressure and current.

The presence of another bremsstrahlung source on high β beamlines was clearly demonstrated by measurements done with various scraper settings. There are two sets of horizontal and vertical scrapers installed on the ESRF storage ring. The measurement shown below was carried out on a high β beamline, which in terms of phase advance is normally well-protected by these scrapers. One can see that, when opening the scrapers completely, a drastic increase in bremsstrahlung was observed. This measurement proved unambiguously the presence of a "scraping" effect made by these new vessels. Monte Carlo calculations would indicate that even with the scrapers in their nominal position, part of the radiation is still due to this scraping effect.

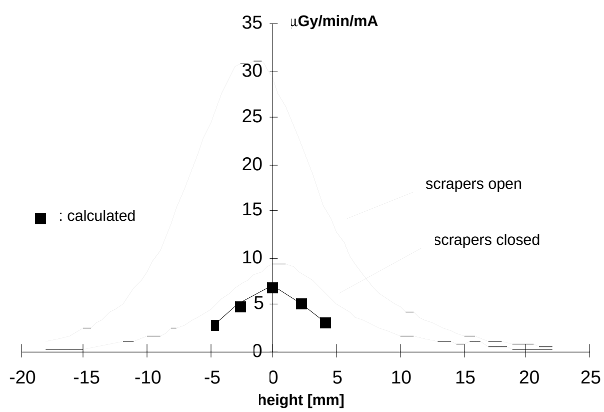

Figure 3: Measured vertical bremsstrahlung profiles for two extreme scraper settings. The expected dose profile from Monte Carlo calculations is also shown.

When looking at these 2 profiles in more detail, one observes a clear vertical offset between the two, indicating indeed a different origin (beam axis for the gas bremsstrahlung, vessel wall for the "scraping" induced bremsstrahlung).

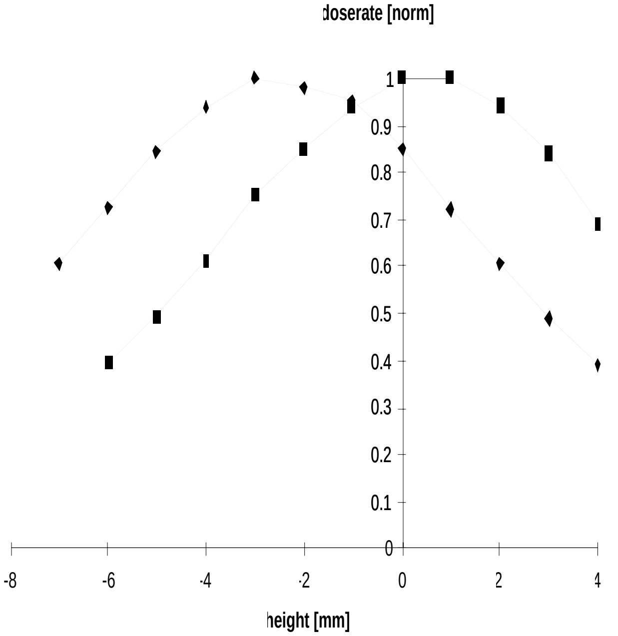

Figure 4: Vertical offset between the two bremsstrahlung profiles.

4 LOW BETA OPTICS

As mentioned above, the increased radiation levels only remained after the initial vacuum conditioning period on those beamlines installed on high β straight sections. The ESRF lattice alternates low β ($\beta_{vertical}$ = 3.51 m) with high β ($\beta_{vertical}$ = 12.85 m) cells. A new lattice was tried out, putting all the cells into low beta optics. The measurements reported above were repeated on the same beamline, with the storage ring operated in this new low beta optics, and the results are shown below. As can be seen, there is no more effect of the scraper position on the measured bremsstrahlung profiles. Also, these new profiles are now slightly lower, corresponding very well with the calculated levels shown in figure 3. This result therefore clearly shows that with this new low β optics, the bremsstrahlung originating from the "scraping" effect completely disappears, and that the residual bremsstrahlung spectrum can be completely attributed to gas bremsstrahlung.

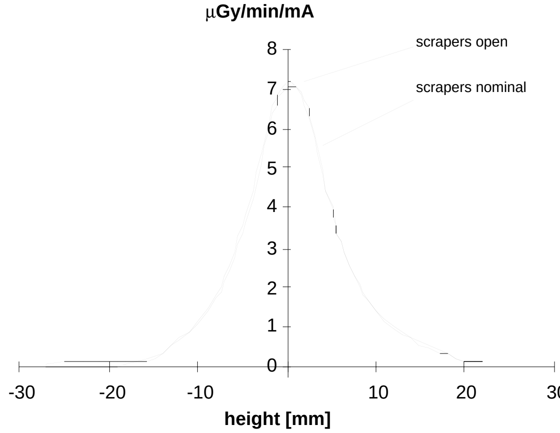

Figure 5: Measured vertical bremsstrahlung profiles for two extreme scraper settings, for the new low β lattice.

We also verified that no extra radiation was measured on the originally low β beam lines.

Since the end of 1996 the storage ring is now permanently operated in this new low β optics, and the bremsstrahlung problems on all the beamlines have dissapeared.

5 CONCLUSION

This experience at the ESRF clearly demonstrated the radiation problems that can be caused by localised beam losses in the straight sections used for beamlines. In the case of the ESRF, the local beam losses were caused by the bottleneck effect produced by the reduced vertical aperture of the new insertion device vacuum vessels. The bremsstrahlung produced by these "scraping" effects can be much higher than the expected gas bremsstrahlung, and produces radiation which is vertically off-centred with respect to the synchrotron beam.

At present new insertion device vacuum vessels are being tested at the ESRF, with a further reduction of the vertical aperture (9 mm internal gap). Up to now bremsstrahlung measurements carried out show a correct vacuum conditioning of these vessels, as well as no evidence of any scraping effect. Further measurements will be carried out before these vessels are installed on operational beamlines.