INJECTION AND FEL LASING WITH FRONT END OPEN AT ELETTRA

K. Casarin, G. De Ninno, F. Iazzourene, E. Karantzoulis, G. Tromba, L. Tosi, A. Vascotto,
ELETTRA, Trieste, Italy

Abstract

In view of the construction of the new full-energy injector at ELETTRA, radiation dose measurements have been performed to study the scenario of beam losses in top-up regime and to explore potential conditions of radiation hazard for personnel. Measurements of gamma and neutron radiation fields have been carried out in the experimental hall varying the injection efficiency while a beamline front-end was open. In this context, FEL lasing experiments were performed while in injection mode. The collected data as well as future developments are presented and discussed.

PRELIMINARY STUDY OF DETECTOR RESPONSE

During injection with front-end open, two ionisation chambers (see Fig.1) produced by PTW Freiburg (model 32002 - volume 1000 cm^3 and model 32003 - volume 10000 cm^3) were placed inside the ring and the front-end hutch to measure radiation yield.

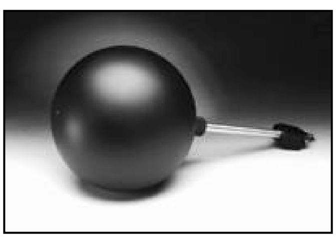


Figure 1: PTW chamber.

The response of these detectors to high intensity pulsed radiation fields was previously investigated to obtain their response curves and to evaluate the saturation level beyond which they start to significantly underestimate the doserate.

With this goal in mind the detectors were placed at different lateral distances with respect to the linac beamstopper, and integrated doses were measured at various currents with the beam hitting the beamstopper itself, as shown in Fig.2,.

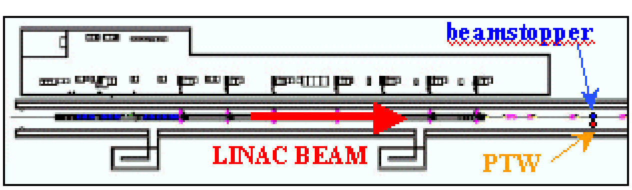


Figure 2: Layout of experiments performed to investigate PTW response to high intensity pulsed radiation fields.

The Linac beam was operated at 900 MeV with a repetition rate of 10 Hz and a pulse length of 70 nsec; the pulse amplitude was varied according to needs. Results are shown in Figs. 3a and 3b.

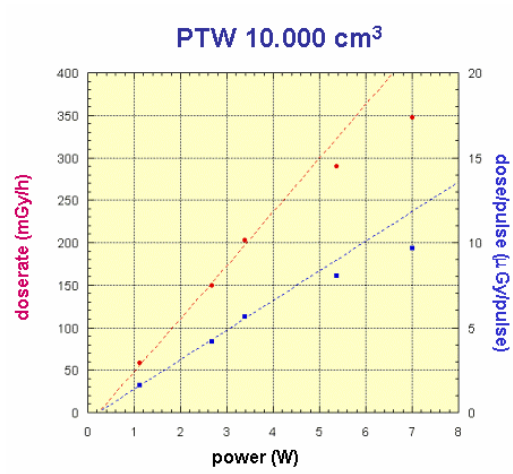
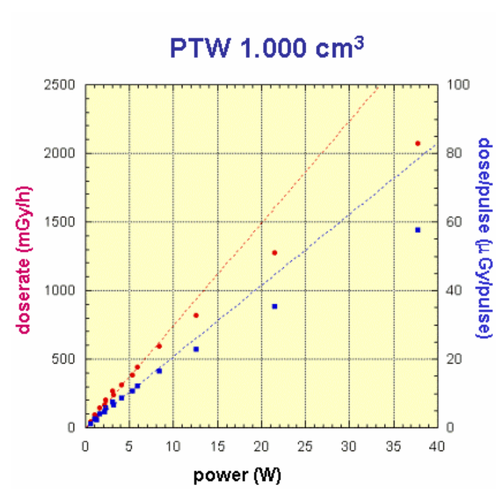


Figure 3a: Response of the 32003-PTW ionization



chamber.

Figure 3b: Response of the 32002-PTW ionization chamber.

The response of the 32003-PTW ionization chamber can be considered linear up to a beam power of about 5 W (doserate ≈ 300 mGy/h), whereas for the 32002-PTW ionization chamber this limit is reached at 10 W (doserate ≈ 700 mGy/h).

INJECTION WITH FRONT-END OPEN.

The great advantage of operating the future new injector of Elettra in top-up mode is that the beam current will be kept constant within 0.1% to 1% of the maximum level.

Safety issues related to injection with open photon shutters and beamstoppers have to be considered in order to design an appropriate safety system and radiation monitoring network [1]-[7]. Preliminary experiments have been carried out to evaluate the radiation levels produced outside the shielding when the beam is injected with one of the beamlines open.

The beamline used for this experiment was the FEL/Nanospectroscopy beamline, the first encountered by the beam after injection. It is an optical-klystron (i.e. two undulators separated by a dispersive section) beamline with an aluminium low gap (14 mm internal aperture) vacuum chamber that can be used, in conjunction with its back-end, at 0.9 to 1.5 GeV to drive a Free Electron Laser (FEL).

Machine behaviour was studied during normal injection conditions. Furthermore, in order to study possible beam loss scenarios during inefficient injection, controlled “bumps” were applied to the beam in the straight section upstream of the operating beamline, to force partial or total beam losses close to the beamline front-end (FE). These bumps consisted of vertical shifts of the beam parallel to the vacuum chamber axis, so as to reduce the local vertical acceptance.

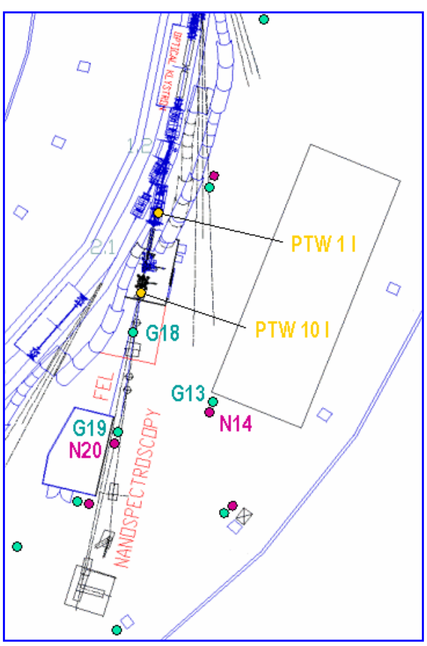


Figure 4: Layout of beamline area showing the positions of gamma (green circles) and neutron (red circles) monitors and PTW chambers (yellow circles). The readings of labelled monitors (G=gamma, N=neutron) are shown in Table 5. Unlabelled monitor readings were comparable with the natural radiation background and are not reported.

During all these experiments, radiation measurements were performed in the machine tunnel close to the front-end, and inside the beamline hutch using the PTW chambers described above. A radiation survey in the experimental hall was carried out by means of environmental Silena gamma/neutron monitors [7] and portable dosimeters.

The layout of the beamline area with the positions of the monitors and ionization chambers is shown in Fig.4. Tables 5a and 5b list the data from PTW chambers and from the gamma/neutron monitors obtained during the experiments both with an efficient injection (no bump) and applying 1 to 4 mm bumps.

	PTW measurements (mSv/h)			portable monitors (μSv/h)
bump	injection efficiency	inside ring	inside FE hutch	outside FE hutch door
∅ mm	77%	9.8	2.07	< 1 γ, n
1 mm	71%	11.3	2.5	< 1 γ, n
2 mm	53%	28.5	8.5	8 γ + 5 n
3 mm	47%	79.2	25.0	30 γ + 23 n
4 mm	8 %	223.4	79.8	50 γ + 36 n

	Silena gamma /neutron monitors measurements (μSv/h)				
bump	G18	G19	N20	G13	N14
∅ mm	0.13	0.10	/	0.10	0.20
1 mm	0.50	0.10	0.12	0.18	0.22
2 mm	1.10	0.10	0.22	0.30	0.50
3 mm	5.30	0.20	0.90	1.30	1.20
4 mm	11.60	0.40	1.70	2.30	2.30

Table 5a and 5b: Data from PTW chambers, portable dosimeters and environmental gamma and neutron monitors (γ=gamma, n=neutron, G=gamma, N=neutron).

Results of the survey outside the hutch (reported in tables 5) demonstrate that radiation detected in the experimental hall in the forward direction is significantly lower than the one measured laterally, next to the door.

This is due to the fact that consistent shielding (25 cm of lead) was placed downstream of the first mirror of the beamline to shield against the products of gas bremsstrahlung during conditioning of the aluminium vacuum chamber. The lateral 5 cm lead wall, present for the same reason, was not always sufficient to shield from losses produced during inefficient injection (2 to 4 mm bumps).

Similar measurements performed as described above, but with the front-end closed, also showed that, under worst conditions, radiation fields were one order of magnitude less than the corresponding data taken with the front-end open.

FEL MEASUREMENTS

A preliminary set of experiments were carried out to study the effect of the storage ring FEL on the instability threshold that limits the maximum current that can be injected in a single bunch.

During their motion, the electrons interact with the ring environment. This interaction manifests itself as an electromagnetic wake field that acts on the electrons and may perturb their stability. The microwave instability [8] is one of the mostly likely observed. It may limit the maximum current that can be stored in a single bunch and leads to an increase of energy spread with consequent anomalous bunch lengthening [9, 10].

In a SR based FEL, like ELETTRA [11, 12], the electron beam is recirculated many times in an optical cavity where it radiates coherently. The multipass interaction of the beam with the radiated power, stored in the optical cavity, induces bunch lengthening and energy spread that cause the FEL to saturate [13].

On this basis, one can argue that longitudinal instabilities and FEL dynamics are competing non-linear mechanisms generating noise, since both effects are based on the increase of the electron beam energy spread and bunch length [14]. In fact, the competition between the two processes can be traced to the mutual feedback between the respectively induced electron beam effects, that can lead to the collapse of one of the other growing effect. If, for example, the laser is able to develop, the instability is completely counteracted even though ready to grow again when, for any reason (for example due to an external perturbation), the laser is switched off.

In this context, one can expect that beam injection when the laser oscillation is established may lead to a higher threshold for the instability that limits the maximum single bunch current. The preliminary set of experiments confirms this trend: the instability threshold turned out to be shifted to 12 mA per bunch while the maximum current stored in the absence of the FEL (identical machine conditions) was 10 mA. This result is in good agreement with the same kind of measurements performed at Duke, where an increase of the single-bunch current of more than 20 % has been found when the machine is operated in a top-up regime and in the presence of the FEL oscillation [15].

More systematic experiments, as well as a dedicated theoretical analysis aimed at modelling the FEL interaction with the instability responsible for the single-bunch current limitation are foreseen in the near future.

SUMMARY

Results obtained from a set of systematic measurements performed during injection with a front-end open have shown that, if the injection efficiency is over 70%, the radiation levels outside the beamline hutch are within the limits provided for unclassified areas. When, however, the beam is forced to be lost along the beamline low-gap vacuum chamber inside the ring, radiation doserates increase significantly.

These experimental results are useful because they help in predicting the radiation fields detectable inside the experimental hall if, during top-up injection, the electrons bunches are not correctly injected inside the ring and are lost along the ring vacuum chambers. Further experiments will be performed to investigate other possible beam loss scenarios (i.e. changing the status of injection kickers or applying different kinds of corrections to the beam orbit to study the beam loss distribution). All the results will be taken into account in designing an appropriate safety system and radiation monitoring network for the new injector.

The top-up regime also revealed itself to be very interesting for FEL operation. A preliminary set of experiments seems to confirm that injecting while the laser oscillation is established leads to a higher threshold for the instability that limits the maximum single bunch current. The possibility of increasing the maximum current compatible with FEL oscillation is an important improvement in the performance of the source in terms of maximum extractable power.

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