Safety systems for the pulse by pulse operation at SPring-8 Angstrom Compact free electron LAser facility, SACLA

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Abstract

SACLA has been operated to get XFEL with one beamline at a time. Recently, two XFEL beamlines are available to upgrade to pulse by pulse operation with different energy for each beamline. In addition to safety system for the normal operation of SACLA, the system were discussed and re-constructed to keep safety during pulse by pulse operation. Many Monte Carlo simulations using FLUKA have been performed in the cases of the mismatich between the electron energy and the field strength of the swing and swing back magnets. To avoid the severe conditions during the operation, the countermeasures such as installation of the local shieldings, expanding the diameter of the electron transport pipe, and arrangement of the area monitors and beam loss monitors, were employed. The experiments have been performed by the simulated trouble tests of some klystrons to verify the countermeasure effectiveness.

1. Introduction

Since 2011, SPring-8 angstrom compact free electron X-ray laser facility, SACLA, which can construct to be 5 beamlines has been operated successfully with one beamline, BL3 for X-ray laser[1]. From March in 2015, two beamlines (BL2 and BL3) for X-ray laser, (another beamline (BL1) is under operation to get EUV laser light) are available, and it is strongly required to upgrade to perform the pulse by pulse operation with different energy for each beamline to use efficently. Besides, the SACLA electron beam will be employed to be the injector of the SPring-8 storage ring with top-up operation to get the higher quality light sources in the near future[2]. In order to do these operations, accelerated electron beams with the different energy must be swung and swung back with high accuracy and high speed. To keep safety under these operations, safety systems at SACLA has been re-evaluated and re-constructed. SACLA accelerated electron beam must be transferred over 200 m at the undulator hall so that the acceptance is very narrow for the mismatch between the electron energy and the field strength of the swing magnet, and there are possibilities to change the electron energy due to one of the klystrons' trouble. It is very difficult to check it in advance with pulse by pulse and the safety interlock system itself. Many Monte Carlo calculations using FLUKA[3],[4] have been performed to avoid the serious conditions during the operation. As the results, some of the countermeasures were employed. One is that the local shields were installed to prevent the high energy electron hitting the bulk shield wall directly, one is that the diameter of the partial beam transport pipe was changed to fix the beam loss points, the other is to be rearranged the area monitors outside the shield wall that link to safety interlock system. In addition, the Cherenkov beam loss monitors [5],[6] were installed to the electron beam transport lines to monitor the position and amount of the electron beam loss.

2. Safety design and the concept for high speed pulse by pulse switching system

The personal protection systems of SACLA such as access control systems and radiation monitoring systems are fundamentally same as the SPring-8 systems to avoid the confusing of the users [7]. The operation control system of SACLA is more strictly constraint in comparison with that of SPring-8 because a lot of accelerated electrons inject into the dump and the experimental instruments must be installed into the forward of the electron beam transport axis. The beam transports are always monitored by using several CTs (Current Transformers) and linked to the machine protection interlock system. In addition, the power of the dump bending magnets is always checked by the safety interlock system to give the permission to operate the machine. Figure 1 shows the illustration of the SACLA beamlines and magnet positions. The operation system has been changed from one beamline operation in a same time for XFEL to pulse by pulse operation with different electron energy as like these 20Hz with 7GeV for BL2 and 40Hz with 8GeV for BL3 beamline, simultaneously. In the near future, we have a plan to operate 6 paths under pulse by the pulse operation with different electron energy. Of these 6 paths, one is to XSBT line to SPring8 ring to get lower emittance and higher coherent light sources [8]. The accelerated electrons are swung 3 degrees by the kicker and pulse swing magnet, and swung back to the beamline BL1 or BL2. However, the pulse by pulse operations with different electron energy are caused severe conditions such as high leakage doses because electron energy mismatch due to such as shift of the kicker magnet timing or the energy inconsistent between the accelerated electrons and the swing or swing back magnets will be occurred. In addition, linac accelerators cause unexpected electron energy change frequently due to miss-fired the one of many klystrons, for example SACLA has 64 units. It is difficult for safety interlock system to check the discrepancy of the electron energy and the magnet powers, in advance. Before starting the pulse by pulse operation, many simulations by using FLUKA were performed. Figures 2 and 3, for example, show the simulation results for the mismatching cases between the swing or swing back magnet power and the electron energy. The 8.5 GeV accelerated electrons with 0.5 nC per pulse hit the shield wall directly after through the transport beam pipe. In these cases, electrons are swung to 3.1 degrees (Fig.2) and swung back 2.9 degrees (Fig.3) with the maximum leakage doses outside the shield tunnel of 0.0034 and 0.12 μSv/ pulse, respectively. To convert the dose rates, the leakage dose will be over 20 mSv/h.

On the bases of the simulations, it is found that high leakage dose will be occurred even though 0.3 % discrepancy of swing magnet power or swing back magnet power, and the safety interlock system cannot easily these discrepancies under the 60 Hz pulse by pulse operation with changing the electron energy. To keep the smooth users' operation, leakage doses have to be constrained as low as reasonably achievable. In addition to the safety interlock system, therefore, it is decided to employ the several countermeasures. One is to install local shields into the electron beam transport line to reduce the leakage doses and specify the production area of the radiation due to unwanted beam losses, one is that area monitors are set outside the

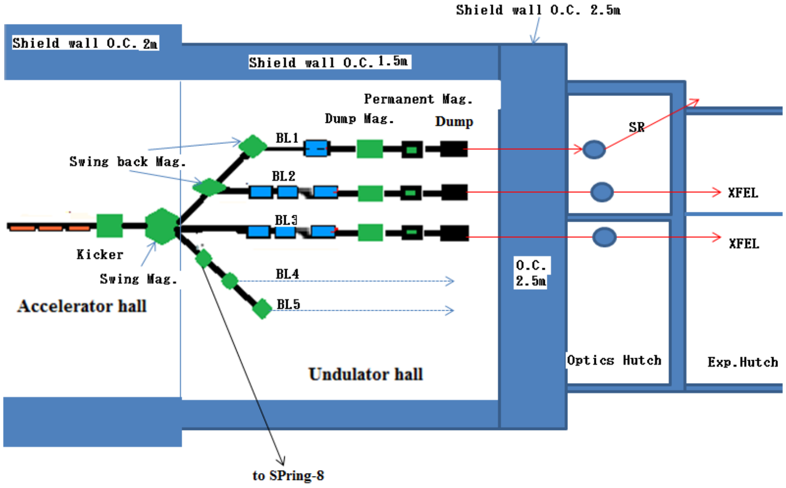
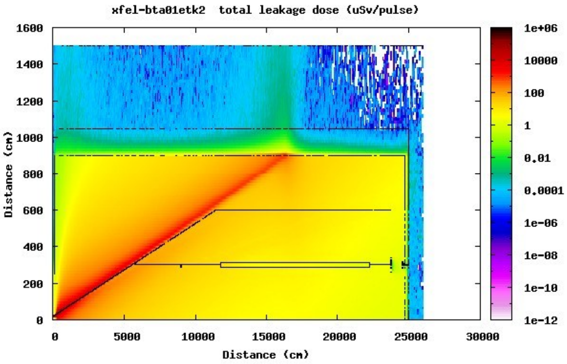


Fig.1 – Illustration of SACLA beamlines.



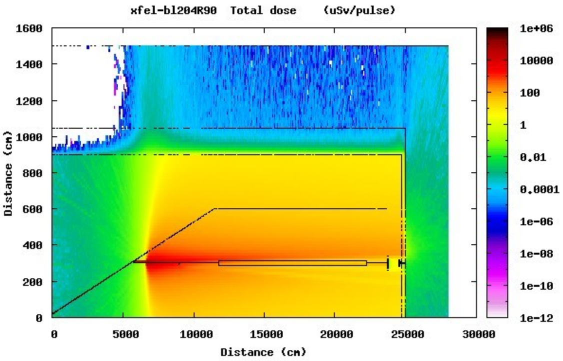


Fig.2 – FLUKA simulation
(a) Swing magnet power mismatch (over 0.1 degrees)

Fig.3 – FLUKA simulation
(b) Swing back power mismatch (0.1degrees less)

shield tunnel where the maximum leakage dose will be appeared in corresponding to the simulations and link to the safety interlock system, the other is that the Cherenkov beam loss monitors are installed to the electron beam transport lines to call operators attention to reduce the unwanted beam losses and the leakage doses as low as reasonably achievable.

The local shields made of ordinary concrete and lead with each 20 cm in thickness were installed into 6 positions of the beam transport lines. The sizes and positions are decided based on the simulations. The first local shield was installed into just after the branch of the electron beam transport line as shown in Fig.4. The second was set to the beam transport line at the intermediate between the branch of the beam transport line and the BL2 swing back magnet. The third was installed into just after the swing back at the BL2 beamline, and the fourth and fifth were set at the upstream and downstream the undulator at BL2 beamline, respectively. The sixth was set at the downstream the swing back magnet of the BL1 beamline. All local shields consist of ordinary concrete at the upstream and lead at the downstream as shown in Fig.4 to prevent the damages by heat loads.

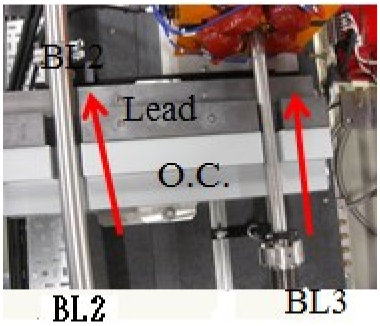
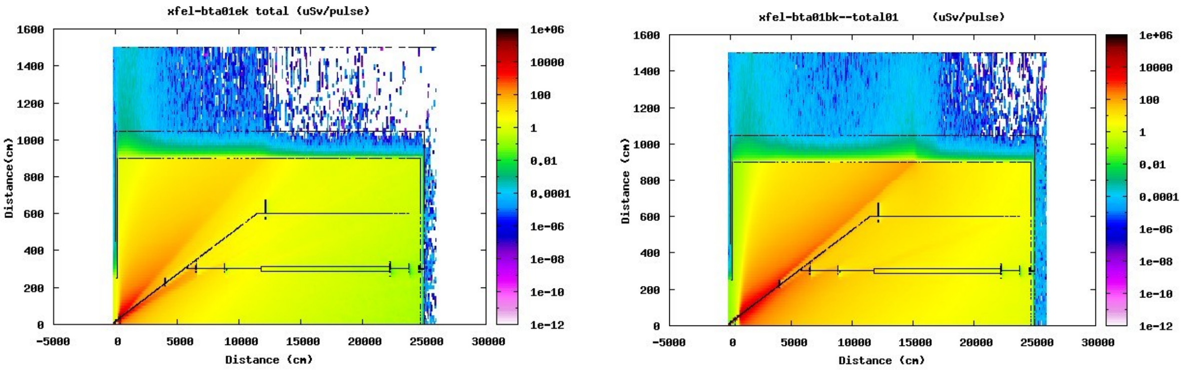
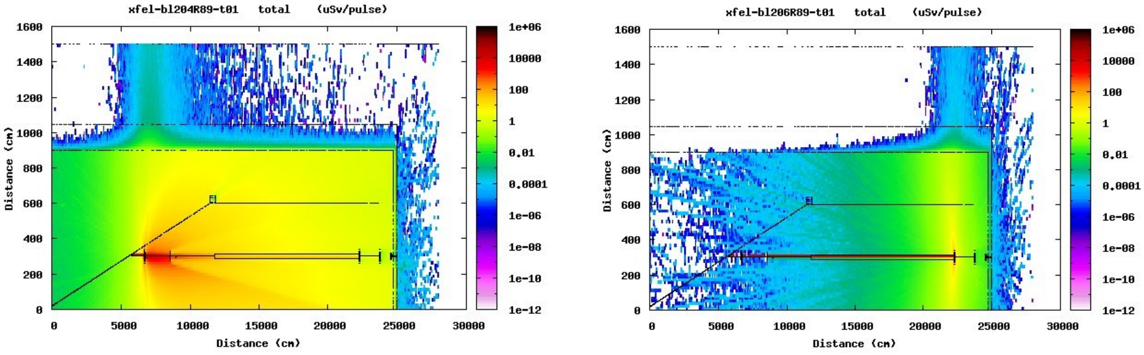


Fig.4 – the photo of the first local shields at the downstream of the branch of the beam transport line. (red arrows indicate the electron transport direction)



(a) 0.1 degrees over *(b) 0.004 degrees over*

Fig.5 FLUKA simulations for mismatch the swing magnet power and the electron energy from the 3degrees



(a) 0.1 degrees less *(b) 0.008degrees less*

Fig.6 FLUKA simulations for mismatch the swing back power and the electron energy from the 3 degrees at BL2 beamline

Figures 5 and 6 show the examples of the results of the FLUKA simulations for the cases of the swing and swing back magnets mismatch with local shields, respectively. In Fig.5, the maximum leakage doses for 0.1 and 0.004 degrees over mismatch cases from the 3 degrees are 0.001 μSv/pulse and 0.00077 μSv/pulse, respectively. In Fig.6, the maximum leakage doses for 0.1 and 0.008 degrees less mismatch cases are 0.0012 and 0.00037 μSv/pulse, respectively. The maximum leakage doses are almost less than 0.001 μSv/pulse for all the cases with the local shields, and the position of the maximum leakage doses are specified as shown in Figs 5 and 6. As the results of the simulations with the installation of the local shields, the positions of area monitors were rearranged in related positions of the unwanted beam loss points to detect leakage dose smoothly.

3. Mismatch test of electron beam energy

Before the pulse by pulse operation, the test has been performed for the leakage dose experiments due to the energy mismatch between the swing and swing back magnet. The mismatch energy tests were performed by the willful failure to fire the one unit of klystrons. The electron energy depends on the sequential position of the misfired klystron so that the tests were performed sequentially with the electron full energy of 7.8 GeV with 10 Hz and about 0.3 nC/pulse. During the tests, the electrons cannot come through the swing magnet and does not increase the leakage doses outside the undulator hall in most cases. However, the electrons can come through the swing magnet and leakage doses are increased in some cases. For example, a part of the accelerated electrons come through the swing magnet and cause high leakage dose when the last unit of klystrons is misfired and about 130 MeV electron energy less, as shown in Fig.7. In this case, about 0.01 μSv/min of the leakage dose was detected by the area monitor at the nearest position of the beam loss point as shown in the figure. All the cases, the simulations are represented the experimental results and the beam loss points are specified successfully.

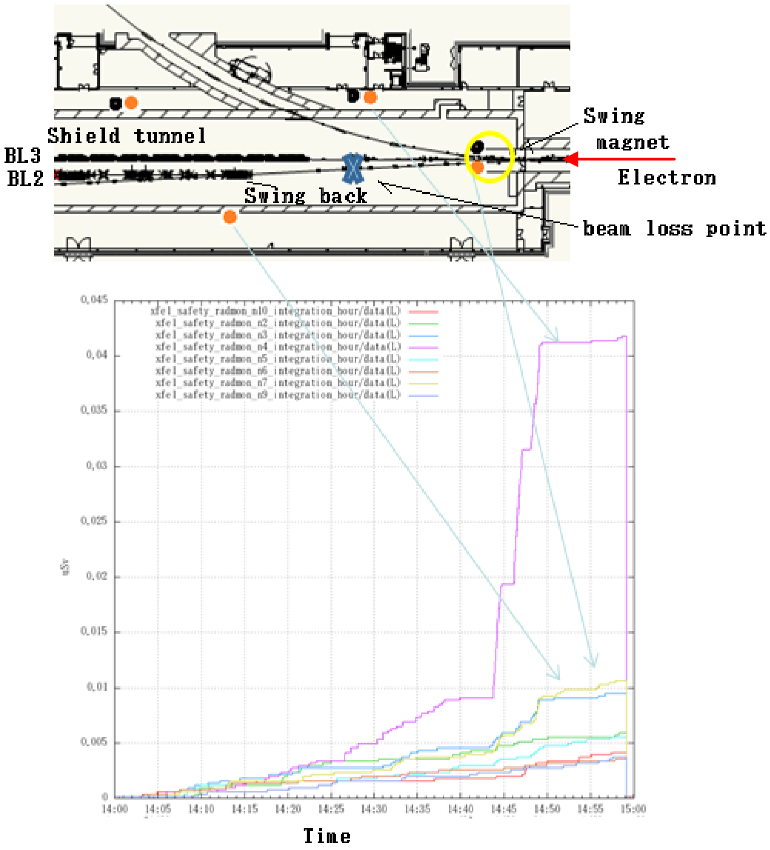


Fig.7 Outputs of the area monitors during the test of the mismatch between the electron energy and the swing and swing back magnet power. The upper figure indicates the position of the monitors around the swing and swing back magnet in the undulator hall and the lower figure shows the outputs of the monitors. (Oranges and blacks are neutron and gamma monitors, respectively. Orange and black with yellow circle are the monitors on the roof. Blue arrows indicate the each monitor outputs. The cross at the beamline from the swing magnet to swing back magnet in the upper figure mentioned the electron beam loss point.)

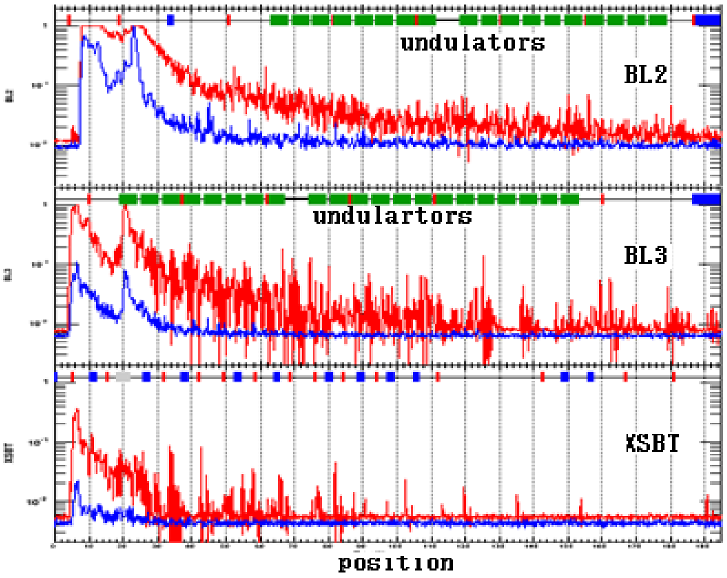


Fig.8 Outputs of the Cherenkov beam loss monitors during the tests of the mismatch between the electron energy and the swing and swing back magnet powers. (The red and blue lines indicate the output of low and high amplitude line monitors, respectively. Green boxes indicate the each undulator unit and blue boxes indicate the bending magnets.)

The optical fiber based Cherenkov beam loss monitors were installed into each electron transport beamlines to measure the amount of the beam loss and the points from the swing magnet to the beam dumps or the electron transport lines. The detection process is that the lost electrons hit the electron transport tube and then produce the electro-magnetic showers, and charged particle like electron or positron crosses the glass fiber and produce Cherenkov lights. The position at the beam loss can be detected by using the time analysis from the pulse trigger signal of the accelerator. The sensitivity of the monitors is less than 1 pC along about the 150 m with the position resolution of less than 1 m. Figure 8 shows the outputs of the Cherenkov beam loss monitors during the tests of the mismatch between the electron energy and the swing and swing back magnet powers. In the SACLA system, two Cherenkov monitor lines were installed for one electron beam transport line to expand the dynamic range of the detection. In the figure, the beam loss point can be found on the BL2 beamline at the downstream of the swing magnet and the upstream of the swing back magnet so that it can be defined the beam loss position that indicates as the blue cross symbol in the Fig.7. By using this system, it is easy to find where and how much the beam losses, and when the high beam loss is occurred, the alarm is announced to call operators' attention to control the electron beam effectively.

4. Summary

In order to operate pulse by pulse with different energy and different beamlines safely, additional countermeasures to the safety system of the normal static operation were taken to reduce the risk of the incidents and leakage doses to keep smooth users' operation based on the principles of as low as reasonably achievable. One is that local shields based on the FLUKA simulations were installed to reduce the leakage doses and specify the position of the maximum dose; one is that area monitors outside the shield tunnel were rearranged on the basis of the simulation with the local shields and linked to the safety interlock system. The other is that Cherenkov beam loss monitors were installed into all beam transport lines to detect the loss points and announce the alarm to call operators' attention.

The test of the safety systems for the pulse by pulse operation was performed to confirm the effectiveness through the operation of the mismatch between the electron energy and swing or swing back magnet power with misfired klystrons. As the results, the safety systems can be reduced the risks of the incidents and the leakage doses due to unwanted electron beam losses, effectively.

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