Radiological commissioning of the MAX IV facility

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Abstract

The MAX IV facility is a Swedish national accelerator laboratory hosted by Lund University. The facility consists of a 3 GeV linear accelerator, a short pulse facility (SPF) and two electron storage rings with energies of 1.5 GeV and 3 GeV having circumferences of 96 m and 528 m, respectively. Presently 6 beam lines are in operation and an additional 8 are funded and are in various stages of planning and construction. Commissioning of the facility started in 2013 and the first regular user operation took place during the first half of 2017.

The linac can be operated to provide electrons to both rings at full energy or to the SPF. The linac is presently operated at 2 Hz but will eventually provide electrons to the rings at 10 Hz (3 nA) and to the SPF at 100 Hz (10 nA). Stationary radiation monitors are positioned around the rings and along the linac and enforce a 4 h dose budget. As a complement a 4 h charge budget on the charge injected to the rings is being prepared for.

Radiological results obtained during commissioning of the linac, rings and beam lines are presented.

Accelerator commissioning

During the radiological commissioning of the linac, SPF, 1.5 GeV and 3 GeV rings a similar approach was used. The accelerated or injected beam was typically intercepted by a closed vacuum valve and the dose rates in the surrounding occupied areas were recorded. The number of available valves used in this manner were ~20 for the linac, ~10 for the SPF, ~15 for the 1.5 GeV ring and ~50 for the 3 GeV ring. The dose rates were typically recorded using a large volume high pressure ion chamber (gamma) and a neutron detector with extended sensitivity up to 5 GeV.

As an example of the commissioning process a segment of the 3 GeV ring is shown in figure 1. The highest dose rates were found when the valve marked by the red circle intercepted the injected electrons. This valve is located just upstream of the straight section.

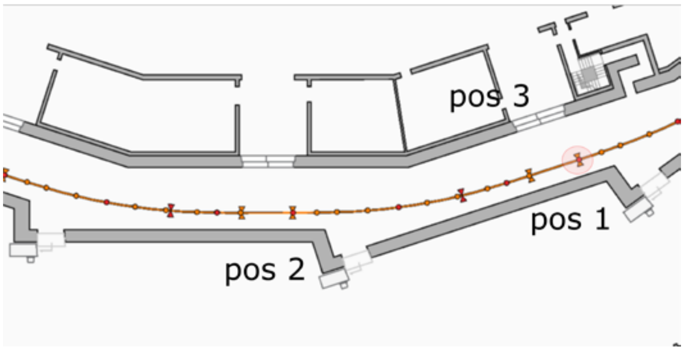

Fig. 1. *A segment of the 3 GeV ring.*

The maximum dose rates for the geometry in figure 1 for an injected current of 0.20 nA were typically 20 µSv/h (gamma) at position 2 and a few µSv/h (neutron) at position 1. At position 3 leakage was found below the doors which amounted to ~400 µSv/h (gamma) at the duct mouth. The effective dose rate was estimated to a few µSv/h. Shielding was subsequently added to the ducts below the inner doors which has resolved the problem. Referring to figure 1, on the ring tunnel roof the dose rates amounted to ~1.5 µSv/h (neutron) and ~1 µSv/h (gamma).

Strategic magnets were also scanned within their allowed limits, defined by the Personnel Safety System (PSS). For instance, the transfer line dipoles between the linac in the basement and the 3 GeV ring on the ground floor were varied between their allowed limits and the dose rates were recorded in the klystron tunnel and around the 3 GeV ring injection section.

Beam line commissioning

One beam line on the short pulse facility (FemtoMAX), two hard x-ray beam lines on the 3 GeV ring (BioMAX, NanoMAX) and two soft x-ray beam lines on the 3 GeV ring (HIPPIE, VERITAS) has been commissioned to date. As an example the BioMAX beam line will be used. The BioMAX beam line is schematically shown in figure 2 where the locations of the undulator, front-end, optics hutch and experimental hutch are depicted.

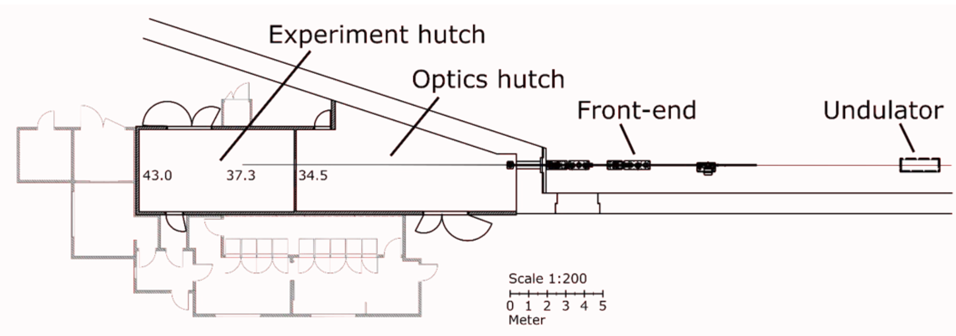

Fig. 2. *The BioMAX beam line situated on the 3 GeV ring.*

BioMAX has an in-vacuum undulator and provides the users with photons in the energy range 5-25 keV. The undulator produces photons with a power of 7.6 kW (at 500 mA stored current) of which 500 W reach the optics hutch, and 50 mW reach the experiment hutch. To date the highest current at which the beam lines at the 3 GeV ring have operated is 75 mA.

The commissioning of BioMAX consisted mainly of 3 parts.

1. At minimum undulator gap and at stored currents of 3, 10 and 50 mA the ring tunnel, optics hutch and experiment hutch walls have been checked for radiation leakage.
2. An ideal scatterer was positioned in the beam in the experimental hutch and the walls of the experiment hutch were checked for radiation leakage.
3. The valve located just downstream of the undulator was closed with open front end and a stored current of 0.5 mA and 5 mA.

The results of the commissioning as outlined above is that all measured dose rates are consistent with background.

Post commissioning

At MAX IV there are approximately 5 radiation monitor stations located along the linac and SPF, 7 around the 1.5 GeV ring and 20 around the 3 GeV ring. Additionally, there are also radiation monitors at the beam lines, for instance 5 around the 3 GeV ring. Their dose budgets have been lowered from a starting value of 20 µSv/4 h to the final value of 2 µSv/4 h. However, the radiation monitors might not always be positioned where the highest dose rates are. In an attempt to overcome this, or at least to limit the possible consequences a charge budget will be introduced. The charge budget is arrived at using the highest measured (or theoretical) yield defined as the maximum dose rate divided by the injected (or accelerated) current. The yield (Sv/C) is coupled to a dose budget (Sv/h) via the charge budget (C/h).

Yield (Sv/C) × Charge budget (C/h) = Dose budget (Sv/h)

The 3 GeV ring where the radiation monitors are approximately 25 m apart is again used as an example. Up until today a current limit on the injected charge of 1 nA corresponding to 14 µC/4 h has been implemented. This current limit has to be modified since i) the injection frequency will soon be increased to 10 Hz, 0.3 nC i.e. a current of 3 nA and ii) we are in the process of educating the accelerator operators to handle the machine without radiation safety staff present 24/7. We see 3 different options to proceed with the charge budget concept.

1. Using the maximum theoretical yield i.e. 74 Sv/C [1] while limiting the possible consequences to 2 µSv/4 h. This results in a charge budget of 27 nC/4 h making it possible to inject the ring at 10 Hz, 0.3 nC during 9 s/4 h.
2. Using the highest measured yield found i.e. 24 Sv/C while limiting the possible consequences to 2 µSv/4 h. This results in a charge budget of 83 nC/4 h making it possible to inject the ring at 10 Hz, 0.3 nC during 28 s/4 h.
3. Using the highest measured yield found i.e. 24 Sv/C while limiting the possible consequences to e.g. 100 µSv/4 h. This results in a charge budget of 4200 nC/4 h making it possible to inject the ring at 10 Hz, 0.3 nC during 1400 s/4 h.

Of the options listed above, 1 and 2 only allow for 27 nC/4 h and 83 nC/4 h, respectively. In order to fill the ring after a beam loss a total of 880 nC is required assuming an injection efficiency of 100% which rules out options 1 and 2. We will thus proceed with option 3, i.e. the dose budget on the radiation monitors will be kept at 2 µSv/4 h together with a charge budget of 4.2 µC/4 h corresponding to limiting the possible consequences to 100 µSv/4 h.

The 3 GeV ring was designed for injection of 1.2 µC/4 h [1]. According to a recent nominal operation estimate the 3 GeV ring will require 0.4 µC/4 h. Table 1 summarizes the different charge budget options for the 3 GeV ring.

Scenario	4 h charge budget (μC)
Design	1.2
1 nA limit	14
Nominal operation estimate	0.4
Opt 1.	0.027
Opt 2.	0.083
Opt 3., 100 μSv/4 h	4.2

References

1 MAX IV shielding

MAX IV DDR

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