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A facility for a few views X-ray tomography of transient processes

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Abstract

A test facility for a few views X-ray tomography of fast transient processes is proposed. It will be made using an existing electron injector. The facility will produce three low-sized short-pulsed almost simultaneous X-ray flashes, so one takes three 2-D images of an investigated transient object from different directions. A procedure of a few views tomography can be applied further to the images. Thus, the flash 3-D structure of the object can be obtained.

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Keywords: A few views tomography; Transient process; Electron beamline

1. The goal

A test facility for a few views X-ray tomography of transient processes will be a unique machine for investigation of short-lived objects. It is also intended to develop components of electron beamlines necessary to obtain several X-ray sources from one electron source and to optimize the design of bremsstrahlung converters. In addition, it will permit to improve 2-D X-ray detectors and to develop a technology of a few views tomography.

2. The facility

The facility (Fig. 1) is based on the electron injector of Novosibirsk high-power FEL [1]. The basic parameters of the injector are placed in Table 1. While operating with the test facility, the injector is to produce short (~200 ns) trains of bunches with the maximum repetition rate within the train. The trains are synchronized with the process in an investigated object and their repetition rate is very low. At the recent repetition rate, a train contains only six bunches, while after the planning upgrade, this number will be 36. Each train is conducted from the injector to kickers with bending and focusing magnets. Two kickers bend one-third of a train each for a small angle upward

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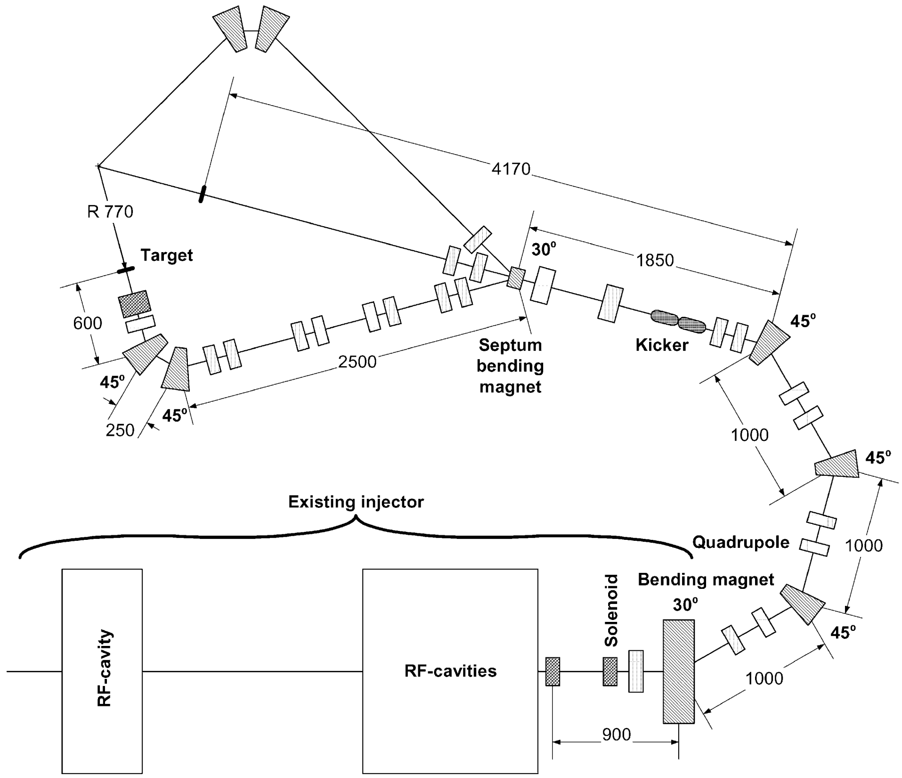

Fig. 1. Layout of the facility.

Table 1
Injector of Novosibirsk FEL

Kinetic energy of electrons (MeV)	1.5
Charge in bunch (nC)	Up to 2
Repetition rate	Up to 22.5[a]
Peak current (A)	20
Initial emittance (πmm mrad)	10
Energy spread (relative)	3×10^{-3}

[a]Up to 180 MHz after planning upgrade.

and downward, so that these parts come through the upper or lower septum magnets or between them. The septum magnets bend the partial trains for 30° in the horizontal direction. They are conducted further to three bremsstrahlung converters and focused there. Thus, one obtains three low-sized (~1 mm) X-ray sources flashing within ~200 ns.

The beamlines of the facility were designed and optimized with a simulation code [2]. Each part before and after the septum magnets are achromatic Fig. 2. Typical rms beam radii in the beamlines are ~5 mm, and the spots on the converters are less than 0.5 mm. The parameters of the beamlines are placed in Table 2.

The facility will exist simultaneously with the first-stage FEL and the full-scale one. The injector beam will be switched between the machines with the first bending magnet.

3. The expected parameters

Let us estimate the parameters of the X-ray sources. Consider an optimal bremsstrahlung converter made of tungsten ($Z = 74$, $\rho = 19.4\,\mathrm{g/cm^3}$). Much more practically feasible tantalum ($Z = 73$) gives almost the same parameters. Gold ($Z = 79$) and lead ($Z = 82$) are significantly better, but the latter claims additional vacuum sealing and cannot be baked

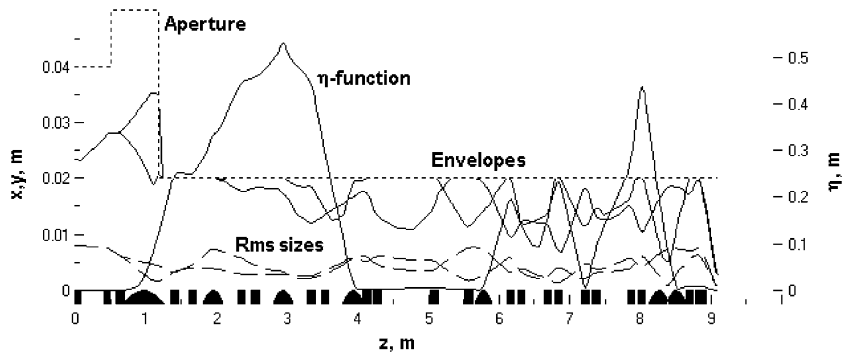

Fig. 2. Beam motion in the facility. Common track and right branch.

Table 2
Parameters of the beamlines

Peak current (A)	20
Regular aperture (mm)	40
Number of bending magnets (including septum ones)	9
Number of quadrupoles	33
Number of solenoids	3
Number of kickers	2
Number of bremsstrahlung converters	3
Estimated beam loss	5%

well. Maximum energy yield from a high-Z optimal thickness target lies within 0.5–1 MeV [3,Fig. 36]. This energy permits to investigate, for example, steel objects of a few centimeter thickness. The optimal thickness is about the track length of electron in the target material, 0.4 mm for tungsten. One can estimate the part of the energy emitted by an electron in the given spectrum by formula [3,(27),p. 122]:

$$\xi = \frac{4}{5}\int_{e1}^{e2} (4(1-e) + 3e\ \ln(e))\ \mathrm{d}e \approx 0.33, \qquad (1)$$

where e is the relative energy of photons. Radiation length for lead is $X_0 \approx 5.8\ \mathrm{g/cm^2}$ [3,p. 129]. Recalculation by formula [3,(28)] gives 6.3 for tungsten. Radiation loss at 1.5 MeV for lead is approximately twice less than high-energy limit, as clear from Ref. [3,Fig. 37]. Thus one obtains the energy emitted by an electron within the given spectrum:

$$\Delta E = E_0\xi\rho d/\tilde{X}_0 \approx 1500 \times 0.33 \times 19.4 \times 0.04/(6.3 \times 2) \approx 30.6\ \mathrm{keV}. \qquad (2)$$

A train of two 2 nC bunches produces 10^9 photons. This formula does not consider the change of the electron energy through the target and absorption inside it, the latter is not significant in this case. So one can expect, say, 5×10^8 photons. Numerical simulation of bremsstrahlung generation in a 0.4 mm tungsten target gives $\approx 7 \times 10^8$ photons. This source permits to obtain 70–100 photons per mm^2 at the distance 1.5 m. After upgrade, one can expect about 3–4 $\times\ 10^9$ photons in one flash.

4. Possible upgrades

In addition to the mentioned above upgrade of the injector, several other possibilities are considered. First of all, the number of X-ray sources can be increased by relatively simple duplication of the basic splitter. All the new magnets and converters can be replicate in this case. Another possibility is to use the accelerator structure of FEL. The maximum energy gain on it is about 12 MeV. One can pass electron beam through the structure twice Fig. 3. In this case the final energy is about 20 MeV, as the cavities in the structure are not equidistant and their RF-phases cannot be optimal for both directions simultaneously. This upgrade

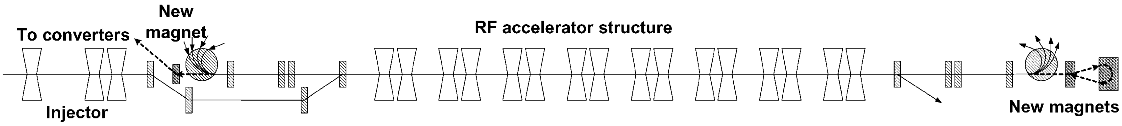

Fig. 3. A 20 MeV upgrade of the facility.

permits to obtain ~3 MeV photons and investigate comparably thick and dense objects.

5. Conclusions

- A project of a test facility for a few views X-ray tomography of transient processes is proposed.
- All the necessary R&D study for it has been conducted. It is ready for mechanical design.
- The facility will permit to investigate short-lived objects in 3-D. Also it is intended to develop the technology of beam splitting and separation for future analogous devices.
- A number of possible upgrades are considered.

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