STATUS OF A 2-MeV CW RF INJECTOR FOR THE NOVOSIBIRSK HIGH-POWER FEL

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Abstract

A 2-MeV injector for the Novosibirsk high power free electron laser is described. It consists of a 300 keV electron gun, one bunching and two accelerating RF cavities with RF generators, a vacuum system, a magnetic system and a beam dump. The electron gun uses a gridded cathode and provides an electron beam with average current 55 mA, repetition rate 22.5 MHz and peak current 2.3 A. The RF system operates at 180 MHz frequency. The CW RF power supply provides up to 260 kW output power. The injector will serve as the beam source for the accelerator-recuperator of the high power free electron laser, which is under construction in Novosibirsk now.

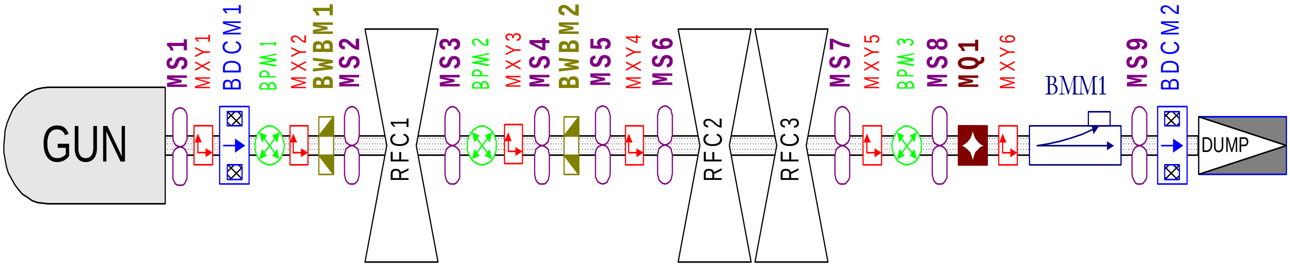

Figure 1: Schematic drawing of the injector. MS - solenoidal lens; MXY - steering magnet; BDCM - beam direct current monitor; BPM - beam position monitor; BWBM - wide-band beam current monitor; RFC - RF-cavity; MQ - quadrupole lens; BMM - beam measurement module.

1 THE FUNCTION AND THE ESSENTIAL FEATURES

The described electron injector is intended to supply high quality electron beam to an accelerator-recuperator (AR) driving a free electron laser (FEL) [1]. The beam is to be supplied in continuous mode and meet rigid requirements of emittance, energy spread, jitter and ripple. There is also a project to use it for high-power millimetre-wave FEL [2]. The injector was assembled and commissioned in 1998 [3] and operates now successfully.

2 THE ARRANGEMENT AND THE OPERATION

The injector (Figure 1) consists of an electron gun, a bunching radio-frequency (RF) cavity and two accelerating ones with RF-generators, a beamline with electron optics, and a set of diagnostics devices. The gun consists of a high-voltage accelerator tube and a thermionic oxide cathode-grid unit manipulated by a snap-off diode based modulator. It emits electron bunches of kinetic energy up to 300 keV, charge up to 2.5 nC, duration 1.1 ns, and repetition rate up to 22.5 MHz. In the first cavity bunches gain time correlated energy spread, after that decrease their duration in free space between the cavities, and finally are accelerated in the last two cavities (Figure 2). The correlated energy spread is compensated in the accelerating cavities and partially due to the space charge effect. Solenoidal magnetic lenses maintain the beam inside the beamline and form its transverse structure.

The frequency of the whole RF-system is 180.4 MHz, the same as in AR. This comparably low frequency permits to obtain high-quality beam after one-cascade klystron-like bunching without higher or subharmonic compensation.

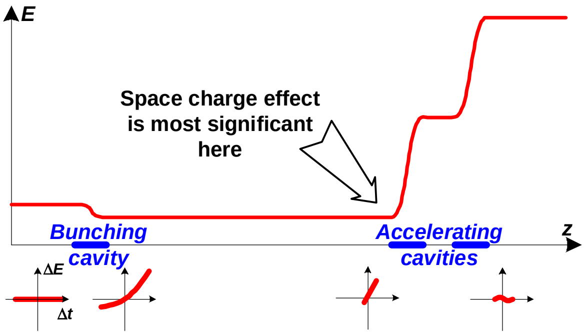

Figure 2: Bunching in the injector.

The basic beam parameters are following:

Full electron energy, MeV		2
Average beam current, mA	up to	55
Peak current, A	up to	25
Repetition rate, MHz		0.02 – 22.5
Pulse duration, ps		50 - 200

3 NUMERICAL SIMULATION AND MEASUREMENTS

The machine was numerically simulated in two stages. The SuperMASON code [4] was used to simulate electron motion inside the gun. Space charge effect and transient effect were taken into account. Then the obtained data were converted and used as the initial ones for the L_PHASE code [5] simulating electron motion through lenses and cavities. All the mentioned effects were taken into account. Both codes consider non-homogeneous circular symmetric bunches. The last code was used to design the machine and to adjust it later. The key question is what phases of RF-oscillations in the cavities with respect to the injection moment and lens strengths one should choose to optimize the beam quality.

To compensate the non-linear dependence of the velocity of the energy bunches should pass the first cavity so that to loose ≈30 keV. The cubic nonlinearity in dependence of the velocity on the longitudinal position is caused by the nonlinearity mentioned above and the sin-like time dependence of the electric field in the cavity. It is effectively compensated by space charge effect at some conditions.

Due to space charge effect and chromatic aberration in lenses the transverse phase portraits of different cross-sections of a bunch differ. To minimize this difference (and hence the emittance) one should find an appropriate set of lens strengths together with the phases of RF-oscillations in the cavities using the code mentioned above.

Typical predicted values of normalized emittance and energy spread of the well-adjusted machine were (2-5)π mm·mrad and 3-10 keV respectively, if the bunch charge was ≈2 nC and the final duration ≈100 ps. Of course, those evaluations don't contain the terms caused by finite electron temperature, electric field distortion due to the grid, and inhomogeneous emission from the cathode.

The longitudinal time structure of the beam was measured with an image dissector tube (IDT). The electron beam was directed to an optical transition radiation (OTR) screen, and the generated light was analyzed with IDT.

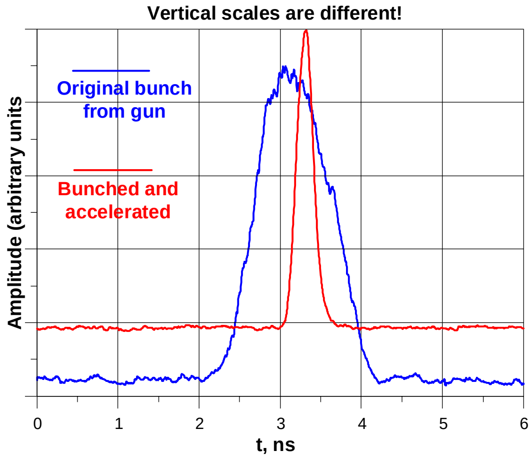

Figure 3: Longitudinal beam structure.

The transverse beam parameters were measured with a set of controlled lenses, and the OTR-screen. A set of beam images corresponding to different lenses strengths is captured and processed together with beamline parameters to derive transverse beam parameters.

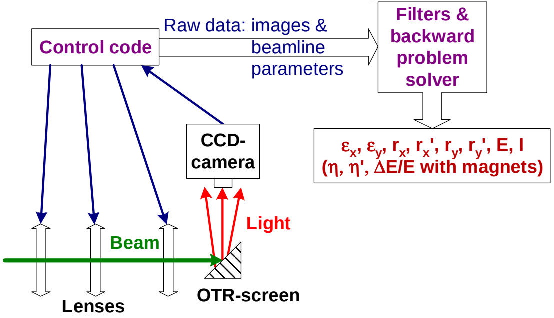

Figure 4: Basic scheme of measurement of transverse beam parameters.

The technique is based on the well known one when the emittance and the Twiss parameters of electron beam are derived from the dependence of the rms beam size on the single lens strength (in the simplest case). In our case space charge effect is taken into account in the form of Kapchinsky – Vladimirsky. It leads to coupling between vertical motion and horizontal one. It also permits to derive the energy and the current form the measured data. Of course, measurement of the energy spread is possible only if at least one bending magnet is included in the beamline, the same as in the original technique.

The normalized emittance measured with this technique is (16±0.5)π mm·mrad. This value is significantly higher than the one obtained from simulation. So probably it can be dramatically improved. The energy spread can't be measured right now as the beamline contains no bending magnets.

4 PROBLEMS ENCOUNTERED AND SOLUTIONS

Initially we experienced great problems due breakdowns in the gun, the high-voltage power supply (HVPS), and the cable connecting them. Breakdowns in HVPS were caused by some weak elements in the high-voltage rectifier. After rejection and changing these elements and installing overvoltage protection the problem was solved. Breakdowns in the gun were caused by the cathode-grid unit. We revised its design and changed the potential distribution along the gun (initially homogeneous). Breakdowns in the cable were caused by ones in the gun and in HVPS as the design of the cable assumes that the voltage changes smoothly. Avoiding breakdowns in the gun and in HVPS leads to dramatic increase of the life time of the cable. Now the whole system operates without breakdowns over a long period. The average current was increased to 55 mA.

As HVPS is a sectioned rectifier, there is some ripple at its output. Odd harmonics were suppressed by making each HVPS section perfectly symmetric. The ripple is also suppressed by a feedback system with an amplifier and a high-voltage transformer. Initially the ripple was ≈3 kV, now it is suppressed by an order.

Jitter and drift of the injection instant leads to dramatic growth of the energy spread of outgoing bunches. It was measured that the jitter exceeds 300 ps and the drift due to both temperature dependence and repetition rate one was > 1 ns. First value was improved by thorough matching of the transmission line between the master oscillator and the gun. Also the scheme of the modulator was revised. The second one was suppressed by a feedback circuit. The measured value in this case is the signal from the first wide-band beam current monitor. Now these values are 100 ps and 10 ps respectively.

To minimize the energy spread at the exit, electron bunches should pass the bunching cavity so they loose some part of their energy there. If the average current exceeds some value (typically ~30 mA), the RF-generator has to absorb RF-power from the cavity to maintain the voltage on the cavity. It claimed significant readjustment of the RF-generator and the control system to enable their operation at the specified conditions.

5 STATUS AND PROSPECTS

Right now the injector operates well. Nevertheless, some problems should be solved. As mentioned above, the energy spread can be measured with the method used only if the beamline contains bending magnets. Right now the injection beamline with a number of bending magnets is being assembled, so we shall be able to measure this important parameter soon.

The life time of the cathode now is approximately a half year. It's a good idea to increase this value several times to make laborious disassembling, assembling and pumping the gun as rare as possible.

Jitter of the snap-off diode based modulator is large enough when the repetition rate is being changed. It is due to its long operating cycle and pronounced dependence on the repetition rate. It leads to increase of the energy spread and additional beam loss when the machine is starting or shutting down. Now several new modulators are being designed.

6 ACKNOWLEGEMENT

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