BUNCHER OF ELECTRON LINAC-INJECTOR FOR A SYNCHROTRON

K.N. Chernov, P.V. Logachev, G.N. Ostreiko, G.V. Serdobintsev, S.V. Shiyankov, G.I. Yasnov
Budker Institute of Nuclear Physics, Novosibirsk, Russia

INTRODUCTION

The application of RF buncher-accelerators for obtaining the short electron bunches is rather known. Their design varies.

Linear accelerators with high-current pulsed beams at energy more than 30 MeV are mainly used as injectors into synchrotrons at modern accelerating complexes. The beam should be previously prepared as series of bunches for injection to obtain stable and effective accelerating regime. In this case RF electron sources would be appropriate for use at the input of a linear accelerator. Such preparing the beam allows one to achieve an effective beam capture into the accelerating regime of linear accelerator for each of the bunches, as well as synchronized operation of the complex with decreased level of radiation background.

RF ELECTRON SOURCE DESIGN

The use of standard diode gun and traditional subharmonical buncher at energy of 100̃300 keV for obtaining picosecond bunches for their further acceleration in a linac faces the problems at intense beam and fixed number of accelerated particles of the order of 1010 per cycle because of great action of degroping longitudinal Coulomb space charge forces. Therefore bunching and accelerating cavities at a frequency of the linac are additionally used, as a rule, in such structures, their cost as high as cost of all the RF gun, which design as well as instrumentation set of an electron source for a linear accelerator are shown in Fig.1. Such RF source allows one to prepare electron bunches with interval between corresponding to the period of synchrotron cavity RF voltage, with dividing each bunch into microbunches, which follow one after another with a frequency of preinjector RF voltage.

In this RF gun electrons are immediately injected from the cathode unit into accelerating gaps of the structure with electric field strength of 150−250 kV/cm (the value depends on the operating conditions). The structure operates at 2856 MHz. This allows one to obtain the particle energy of 0.7−1.5 MeV, decrease Coulomb space charge forces action, and cut the length of a drift gap, where a short bunch is formed.

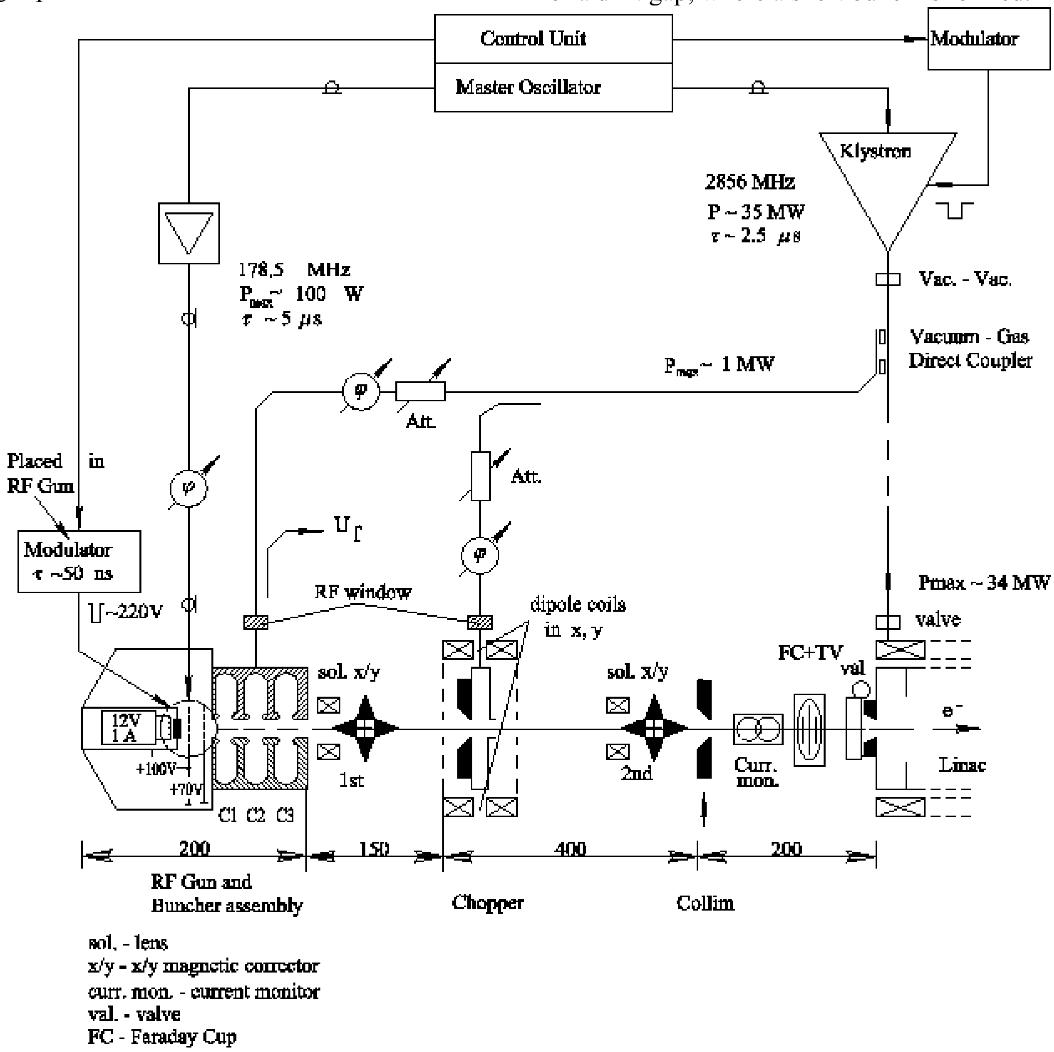

Fig. 1: Sketch of RF gun buncher/chopper system

RF electron source channel towards the beam motion consists of the following parts (see Fig.1): RF source – cathode-grid assembly (tetrode), accelerating section for energy of 0.7×1.5 MeV, focusing solenoid, beam center position corrector, focusing solenoid, quadruple lenses, RF chopper, collimator.

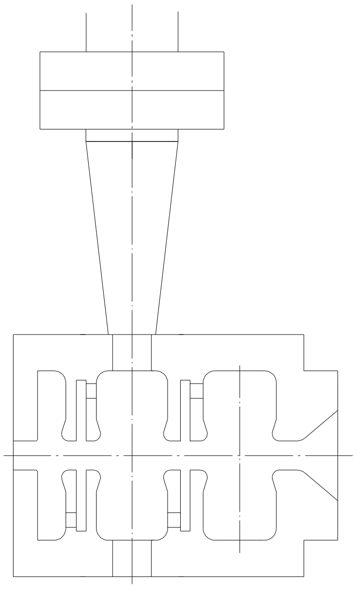

Fig. 2: Accelerating section

Thermocathode with two-grid control (tetrode) placed at the accelerating section input is used in this design as an electron source. The previous forming of electron bunches takes place in the tetrode. The bunch duration depends on a voltage value at the tetrode first control grid, as well as on RF field amplitude (178.5 MHz) in the gap cathode-first grid. The number of bunches is defined by the turn-on voltage pulse duration at the second control grid. For example, for 50 ns turn-on pulse we will obtain 9 bunches with repetition frequency of 178.5 MHz. Current level and bunch series pulse duration are controlled at low-level operation mode of the gun cathode-grid unit (tetrode), with the grounded second control grid being in the same plane as the face wall of the first accelerating gap. Cathode diameter is about 11.4 mm.

Accelerating section is a biperiodic structure with π/2 operating mode, it contains 3 accelerating gaps and 2 coupling cavities (Fig.2.). Type of oscillation is TM_{010}. An electron bunch is divided into several microbunches in the first accelerating gap under the force of RF accelerating field (2856 MHz). Then the beam is additionally accelerated up to the needed energy in the second and third gaps of the accelerating section and gets an energy spread needed for the further bunching in the drifting tube. RF chopper operating at a frequency of 2856 MHz is used in the shown design for the separation of the beam particles by energy, as well as the collimator to removing the electrons from the channel, which are out of the phase area captured into the linac accelerating regime. Focusing solenoids, quadruple lenses together with correctors of the beam center position from the linac axis are used for containment of the beam within the fixed dimensions. Beam current and position meters are used for control. Buncher and RF chopper are fed by RF power extracted form one of the linac powering klystrons, with power consumption not more than 1 MW in 4-5 μs pulse.

BEAM DYNAMICS

Beam dynamics at the inherent points of the buncher RF channel is shown in Fig.36. As it was mentioned above, the previous forming of the electron beam takes place in the cathode-grid unit. Current density distribution along the beam after the second tetrode grid is presented in Fig.3. The series containing 9 such bunches will be delivered to the input of the accelerating section, provide that turn-on voltage pulse with duration of 50 ns fed to the second grid. Bunch repetition rate for the series comprises 178.5 MHz (16-th subharmonic of the linac frequency). Only one of 9 bunches is presented in Fig.3. For the described operating mode of the cathode-grid unit every bunch is divided into 4 microbunches by the action of 2856 MHz RF field after the first gap of the accelerating section. RF field strength in the accelerating cavities of the section is 170 kV/cm. Fig.3 also presents the distribution of the microbunch current density after the first cavity. Only one of 4 bunches is considered for the further describing of the beam dynamics, because they are all similar and their mutual Coulomb influence may be ignored. The next figures present the time history of the beam current and microbunch particle energy along the channel and at the linac input (output of the RF buncher-accelerator).

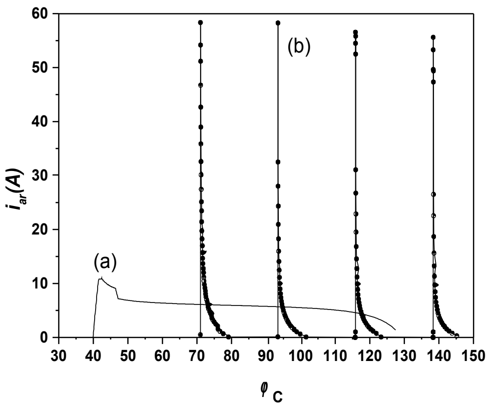

Fig. 3:Bunch current pulse at the tetrode output (input of the structure) (a);
(b) – microbunches at the output of buncher-accelerator;
φ_C – the current phase (degrees) at 178.5Hz.

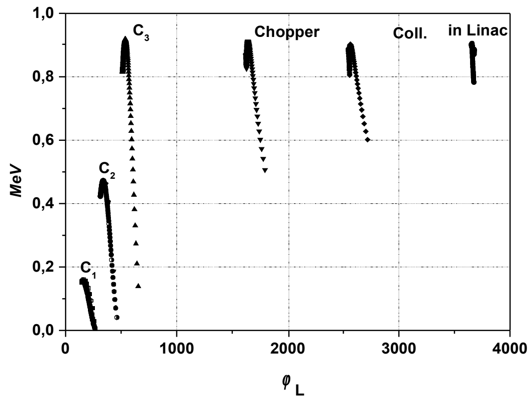

Fig. 4: Time history of the microbunch energy from the buncher-accelerator input along the channel through the chopper, collimator, up to the linac input.
φ_L – the current phase (degrees) at 2856 MHz, C_1, C_2, C_3 – accelerating gaps of the structure

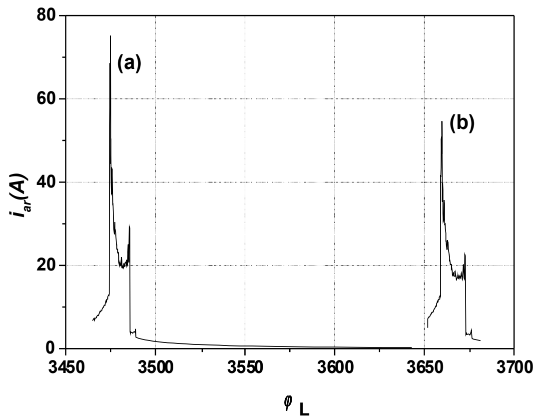

Fig. 5: Microbunch pulse current after the chopper before the collimator (a)
and after the collimator at the linac input (b)

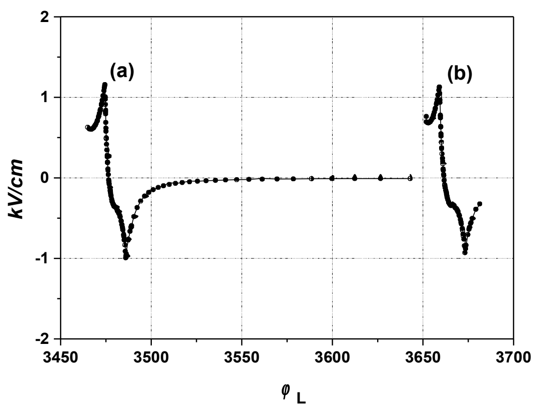

Fig. 6: Distribution of the microbunch space charge longitudinal electric field component:
(a) – before the collimator, (b) – at the linac input

CONCLUSION

All the cathode pulse current in RF electron source is divided into 4 electron microbunch groups with a repetition rate which is synchronous with the frequency of the synchrotron cavities. Microbunch repetition corresponds to the linac frequency. In this case every microbunch is bunched and effectively captured into the regime of further acceleration by the linac and synchrotron without beam current losses. Low-power RF chopper may be turned on for the additional separation of the number of particles within every microbunch by a phase length and cleaning the charge between bunches down to background current level. In this case only local bio-protection is required in the collimator area for the energy up to 1.5 MeV at the linac input, that is essentially cheaper than bio-protection for the full energy of 30-200 MeV at the synchrotron input. The length of RF gun channel is much shorter and its vacuum value is smaller than that of high-voltage diode gun with a subharmonic buncher, so the amount of required vacuum pumps, adjusting devices, and magnetic accompanying elements is smaller, as well as their total cost is less. Moreover, high-voltage power sources for thermogun or high-voltage pulse modulators are not required, and there is no need in the high-voltage gun insulation. Low-voltage power sources with insulation up to 1000 V are used in the tetrode for the electron beam forming.

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