THERMO-CATHODE RF GUN FOR BINP RACE-TRACK MICROTRON-RECUPERATOR

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Abstract

In 2007 the thermo-cathode RF gun for the Budker INP energy recovery linac (ERL) was designed. The RF gun is capable to emit the electron bunches with the energy of 300 keV, average current of 100 mA, and repetition frequency of 90 MHz. The new injector is adapted to the existing RF system for beam bunching, accelerating and injecting to the linac of the microtron. Its advantage is the absence of high potential of 300 kV at the control circuits of the cathode; therefore the maintenance is simplified. Also due to the absence of the cathode back bombardment by residual gas ions in the RF cavity, the lifetime of the cathode is increased and the obtaining of the repetition frequency up to 90 MHz becomes feasible. In the paper the main characteristics of the injector, its design and results of beam dynamics calculations with optimised regimes are presented.

INTRODUCTION

The linac of the ERL consists of 12 accelerating cavities operating on frequency of 180 MHz [1]. The same cavities are used in the injection system.

The new RF injection system will consist of RF gun (cavity updated to 90 MHz), the bunching 180 MHz cavity with first 1.5 m drift section followed, and two accelerating cavities with the second 8 m drift section followed (see fig.4b). Electron bunch characteristics (see the table 1) will be obtained by applying the follow items: unique grid cathode assembly into RF cavity inserted and replaceable electronic control system allow obtaining short bunches emitted. Cavity special electrodes forming the accelerating field distribution that compatible for obtaining minimal bunch emittance from the grided cathode. Adjusting of the phase and amplitude (regime optimizing) of RF field both in the RF gun cavity and in bunching cavity allow obtaining the minimal bunch length and/or minimal bunch emittance at the exit of RF injection system. These settings also imply the reducing of bunch energy spread. The next important item is the adjusting of the field strength of focusing solenoids disposed in the RF injection system. These allow compensate the emittance growth in the RF injection system and reduce the beam transverse size.

RF GUN CAVITY

The RF gun cavity (see fig.1) is the same as the other bi-metallic cavities used in the ERL RF system. Its resonance frequency was decreased down to 90 MHz by the copper insertion having the capacity electrode at the top. It was designed by using of the SLANS code [4].

Table 1: RF Gun and Injector Characteristics

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RF gun beam energy	0.295 MeV	
RF gun bunch duration (FWHM)	1 ns	
Beam emittance just after the grid	23 μm rad	
Bunch repetition frequency	≤90 MHz	
RF gun maximum beam current	≤120 mA	
RF gun cavity input power	54 kW	
Injector system beam energy	1.5 MeV	
Injector system beam current	≤100 mA	
Injector rms bunch emittance	14.5 μm	27 μm
Injector rms bunch length	12.3 mm	7.7 mm
Injector rms bunch energy spread	12 keV	
RF input power of bunching cavity	-8.2 kW	
RF input power of acc. cavities	271 kW	
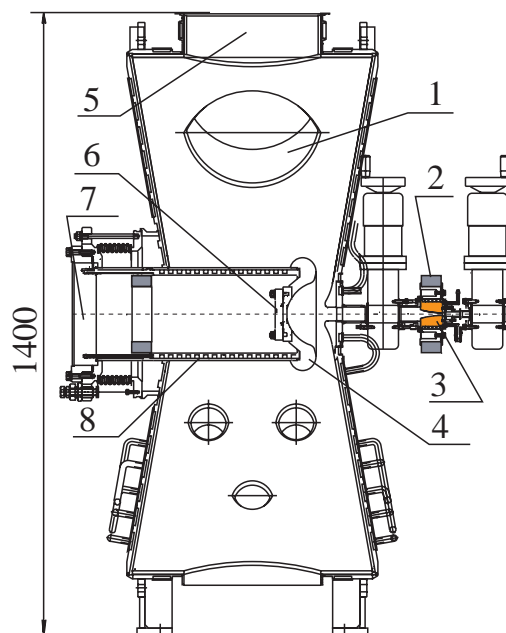
Figure 1: RF gun layout. 1- plunger hole, 2-focusing solenoid, 3-collimator, 4-capacity electrode, 5-input power hole, 6-cathode-grid assembly flange, 7-adjusting mechanical unit, 8- water-cooled copper insertion.

The insertion is welded to the cavity wall through the thin copper membrane. The capacity electrode has special shape to minimize the field on it surface and to provide the focusing effect and required electric field at the grid of cathode assembly in the centre. The thin copper membrane ring can be slightly deformed when frequency initial adjusting is required or when the transverse alignment of cathode is required. The mechanical unit having large bellow disposed behind the cavity provides these deformations.

Two plungers disposed on the cavity cylinder wall make the fine frequency tuning.

GRID CATHODE ASSEMBLY

The RF gun employs a replaceable grid-cathode assembly to control the current waveform. The numerical simulations were done for Russian cathode of metal-ceramic tube GS-34 (see fig.2). There may be the EIMAC type of the cathode instead. Cathode diameter is 12 mm. The fine rectangular grid is placed 170 μm from the cathode. The grid cells have sizes of 150×720 μm with rectangular wires of 40×40 and 60×60 μm.
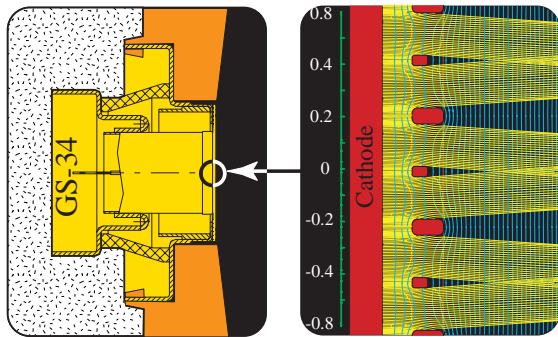

Figure 2: Cathode-grid assembly layout. Emittance dilution of the beam flowing through the grid is demonstrated.

The grid cathode assembly together with its electrical driving equipment provides the electron bunches with 1.5 A peak current, 1 ns duration and maximum repetition frequency of 90 MHz. The cathode driving electrical unit is disposed inside a special replaceable cylindrical box in the RF gun cavity insertion.

BEAM BUNCHING

In order to get a short bunches at the entrance of the linac the particle velocity (energy) modulation along the bunch is applied. For this purpose the bunching 180 MHz cavity is used. The particles from the head of bunch get less energy then the ones from the tail. As a result, the head and tail particles are moved to each other during bunch passing of the drift space after the bunching cavity, and the bunch length decreases at the end of the drift space.

The energy distribution of particles along the bunch must be close to a linear in order to get shortest bunches.

The sin-like nonlinearity of the energy variation obtained in the bunching cavity compensates the nonlinear energy-time dependence, which caused by the RF gun 90 MHz accelerating field. In the fig.3 this energy distributions optimized by ASTRA code are demonstrated.
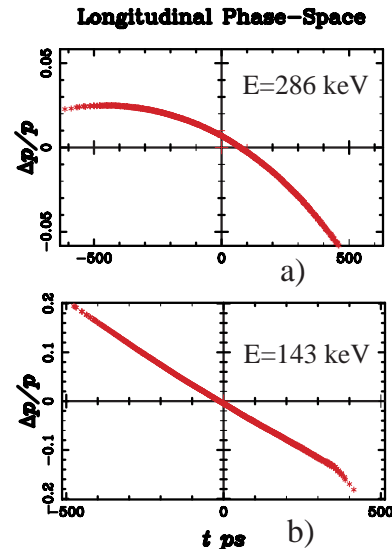

Figure 3: a) Particle energy distribution along the bunch just after the RF gun; b) particle energy distribution along the bunch just after the bunching 180 MHz cavity.

In the simulations both drift spaces, 1.5 m after the bunching cavity and 8 m after the pair of accelerating cavities, were taking into account. The length of first drift space has been optimized in the calculations.

In fig.3a two bunch length behaviors along the RF injection system is depicted. These two different regime optimizations lead to the minimal bunch length or minimal emittance at the exit of the RF injection system. The energy spread of bunches in the first case also decreases at the end of injector. In the second case the correlated emittance is slightly increased.

EMITTANCE GROWTH COMPENSATION

The minimal emittance in RF injection system is obtained by three ways: minimizing of the initial emittance from the cathode, cutting hallo particles by the collimator, and emittance growth compensation in the beam line of the RF injection system by focusing solenoids.

The initial cathode beam emittance grows due to the disturbance of beam flow laminarity by the cathode grid. This disturbance will be minimal if the electric field values before and after the grid are equal [2]. So as the cathode-grid field must be 0.5 MV/m for the 1.5 A peak current it is desirable to have the same field downstream the grid. It is made by special shape of cavity electrodes around of the cathode placing (see fig.1). The field strength in the cavity gap increases from 1 MV/m at the grid up to 12 MV/m. In such a field its radial component

focuses electrons significantly. Because the electric field is variable the bunch slice emittance has very inhomogeneous distribution along the bunch (see fig.5).
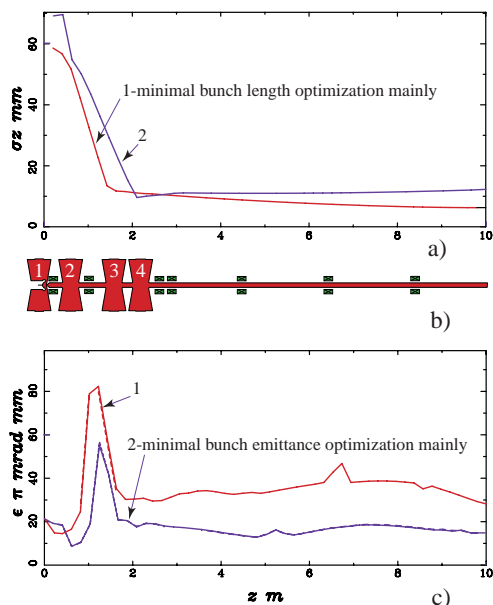

Figure 4: a) Bunch length behavior; b) RF injection system layout: 1-RF gun 90 MHz, 2-bunching 180 MHz cavity, 3, 4-accelerating 180 MHz cavities; c) Bunch transverse normalized emittance behavior for two optimization regimes.

The other reason of the disturbances is the transverse size difference of the grid wires. This disturbance is demonstrated in the fig.2, it was numerically simulated by USAM code [3]. For the simplicity of resolving the large number of grid wires in the transverse region, only a single cell of the gridded structure was simulated. Periodic boundaries were assumed so that the geometry approximates the rectangular regions 150×720 μm as a concentric ring cells in the gun structure. The calculated emittance of bunches in this cathode-grid assembly and their current waveform is presented in fig.5.

Due to significant RF focusing in the cavity gap the bunch head and tail having small space charge density are the source of hallo particles with a large emittance. As it shown by ASTRA simulation [5], due to the cutting up to 20% particles by the collimator (≤6 kW), the emittance becomes better by 30-50%, and energy spread - by 25%.

The emittance of the bunches in the beam line of the RF injection system dilutes mainly due to the space charge forces which acts on the bunch particles by different strength along the bunch because the different charge density in all bunch slices are implied.

In order to compensate the emittance growth and to reduce beam size in this beam line, the magnetic focusing by 8 solenoids is applied. In the reality the beam line has some inclination parts into the bend magnets but we assume in our simulations, it is a straight one. In Fig.4b

the simple scheme of the RF injection system used in dynamics calculations is plotted.
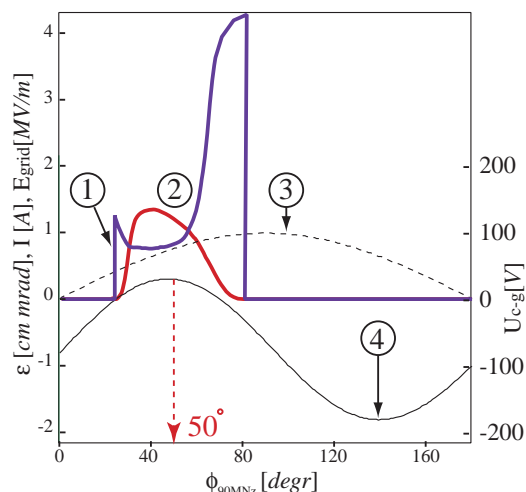

Figure 5: 1) Slice emittance behavior just after the cathode grid; 2) bunch current waveform; 3) RF 90 MHz electric field behaviour downstream of the grid; 4) cathode-grid 180 MHz voltage behavior (U_{c-g}).

In the new RF injection system, all existing solenoids also will be used. Only two solenoids are added upstream and downstream of RF gun, one of them is applied as a bucking solenoid for compensating magnetic field in the cathode to avoid the emittance growth caused by that field.

That magnetic field strength in each solenoid has been optimized by ASTRA simulations [5] to get a minimal emittance at the exit of RF injection system. These optimizations were begun from the first solenoid, then on the second one, and etc. The field strength values is obtained in range of 11÷27 mT, we are not listed it here. As a rule, in such optimizations the transverse size of the beam in the same place also tends to be a minimal. In Fig.4 the resulting behaviors of beam emittance and bunch length along the RF injection system are plotted.

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