800-keV ELECTRON INDUCTION INJECTOR WITH HIGH AVERAGE POWER

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Abstract

For many applications of intense electron beams, including flash radiography and free-electron lasers, multikiloampere currents and low emittance are required. The report deals with the development of an injector ensuring these demands.

Design parameters of the injector are 800 keV beam energy, 2...5 kA current, 80 ns pulse flat top and 100 Hz repetition rate. The average power of the series of pulses is 40 kW.

The injector contains seven induction modules in series to generate 0.8 MV diode potential. The voltage contributions of seven modules, at 120 kV each, are summed along the cathode stem as it threads through the seven units. The modules use amorphous alloy and permalloy cores. The injector has been designed to provide two modes of operation: with a low and high current electron beam respectively. A velvet cathode and a mesh-less anode are used to produce an electron beam with the current of 2 kA and the brightness of 2.4 10^3A/(cm rad)^2 in the first mode. A 800 keV, 5 kA electron beam is derived by a mesh anode in the second mode. The modules of the induction injector and its parameters are described in this report.

1 INJECTOR DESIGN

1.1 General configuration

The injector consists of a high voltage generator, seven induction modules, a ceramic cone insulator and a vacuum tank with an accelerating gap. The electron source mounted on the stem consists of a velvet cathode placed on a field forming electrode. The tapered insulator assembly separates the oil-filled induction modules from the vacuum diode. The generator [1] is a two-stage magnetic power compressor with a thyratrons switch. The voltage pulse is produced by a water-filled pulse forming line (PFL) with the impedance of 3.3 Ohm. PFL is connected to the induction cells by using two parallel rigid 20 Ohm oil transmission strip lines. Each of the induction cells has six identical connnections. Two of them are used for line connections, and four for compensating water resistors that load the pulse power source in parallel with the cell. The injector design is shown in Fig.1.

1.2 Induction cells

The magnetic material in the 1.5 m tank is packaged into seven independent 120 kV induction cells. Oil is used as dielectric and cooling fluid surrounding the magnetic material. The cathode stalk of 105 mm O.D. runs in the center of the injector and the full diode voltage appears across the A-K gap at the load end. The actual average effective length of each cell is 180 mm, giving an accelerator gradient of 0.7 MV/m.

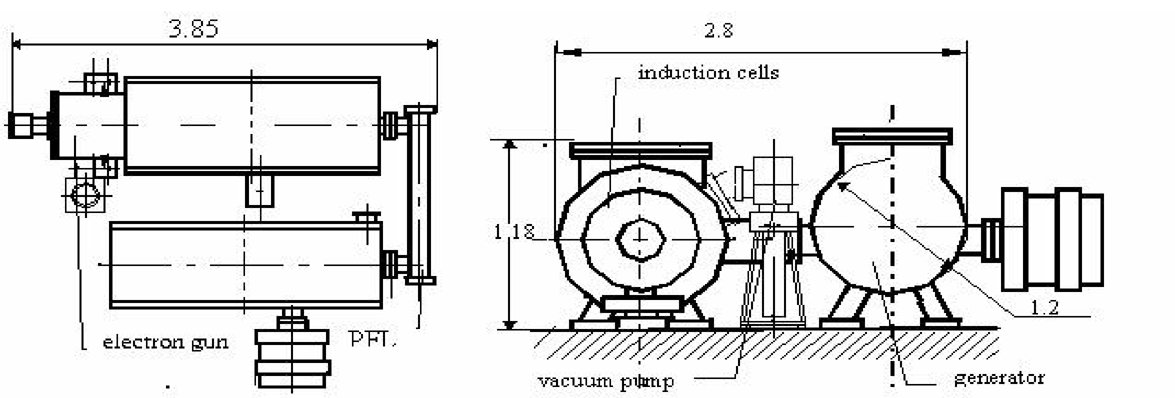

Figure: 1 The injector design.

The four of the seven induction cells consist of five 24 kV permalloy cores with 200 mm I.D., 380 mm O.D. and 25 mm thickness. The other three cells consist of seven 17 kV amorphous alloy cores with 300 mm I.D., 430 mm O.D. and 20 mm thickness.

Particular attention has been given to the design and construction of the induction cell to minimize the voltage between amorphous alloy layers in the cores. In order to solve this problem a high voltage gap is situated in the mid-plane of the induction cell. After calculation of the voltage distribution inside the induction cell we reached the following conclusion. Under the operating conditions wave effects are insignificant as a result of attenuation in amorphous alloy.

The voltage across each core is a vector sum of a curl field and an electrostatic field. It is important that the curl field is the same on each core, and the electrostatic field is different and depends on the capacitive division of the voltage and the core position inside the induction cell. In our design, the radial voltage on the face surface of the cores is no more than one half the voltage over the gap. As a result, the voltage between amorphous alloy layers in the cores is no more than (13...15) V, assuming that the operating conditions of insulation between layers are acceptable. To make the cores, a new technology was used [2]. The insulation coating with high dielectric characteristics is applied during the winding. The computer assistance used during the process of termomagnetic treatment allows to impove magnetic characteristics and reduce the core weight. For example, the experimental results of amorphous alloy 9KCP cores testing show that the puncture voltage is no less than 12 V/wrap, ΔB is 2.2 T and the magnetisation field is no more than 2 kA/m.

The value of magnetization current of the injector amorphous alloy cores was measured without the beam. It is about 2.0 kA under the following conditions: the voltage is 13 kV, the time is 80 ns. The voltage and curent waveforms are presented in Fig.2.

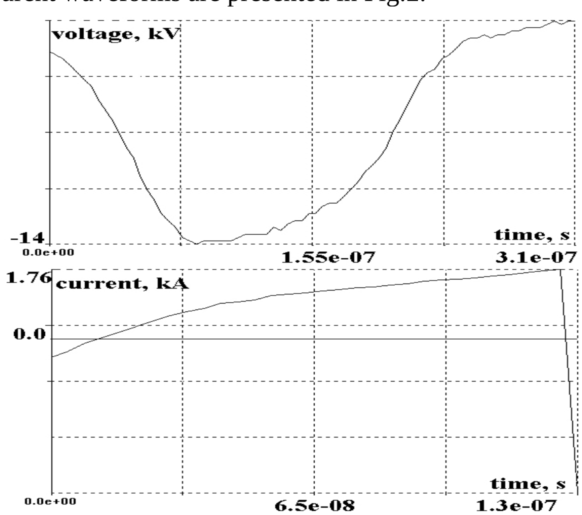

Figure: 2 The voltage and curent waveforms.

The design induction cell parameters provide the core current no more than (2.5-3) kA. Consequently, the core efficiency is (40-44)% in the first mode and (62-70)% in the second mode which that is not bad. These data allow to investigate pull of design parameters of the injector on the waveform of the beam current. The induction cells with the transmission strip lines and PFL were modeled using MC3 simple circuit code. Previously, equivalent parameters of the circuit have been calculated analytically. The waveforms of the current for two modes of the injector operation are shown in Fig. 3. As shown, the droop of the pulse current is nothing more than 10%. This is ensured by a matching water capacitor.

1.3 Electron gun

The cathode assembly is mounted at the small diameter end of the ceramic cone insulator. It consists of a focus electrode, a velvet cathode and a bucking coil. In the first mode, the electron source is a 80 mm diam velvet cathode. The purpose of the focus electrode use is to aid in focusing the beam and to minimize the electric field enhancement at the edge of the emitter. The focus electrode made from the stainless steel has the field stress no more than 150 kV/cm. The A-K gap is about 50 mm and the anode aperture is 90 mm diam.

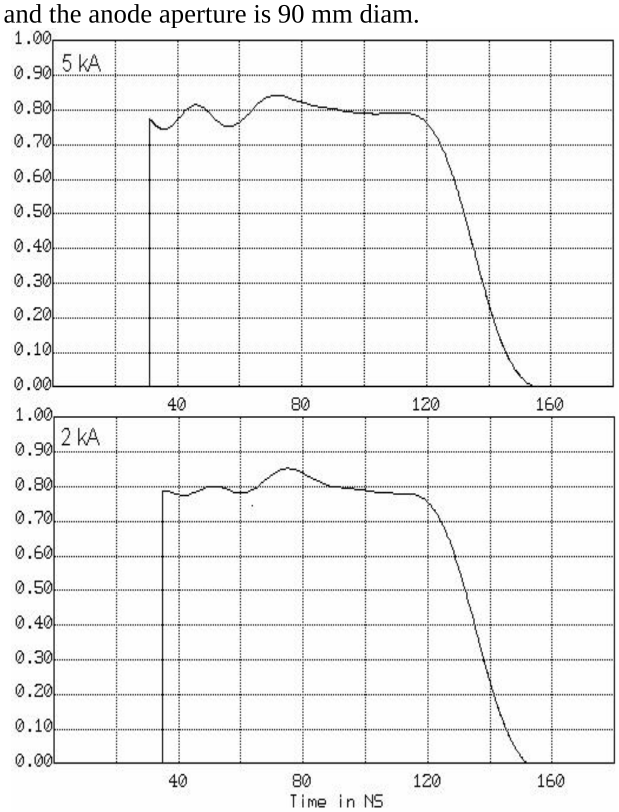

Figure: 3 The wave forms of a current for two modes of injector operation.

The cathode is designed to be operated with nearly zero magnetic field component normal to its surface in order to minimize the canonical angular momentum of the extracted electron beam. This is accomplished with two coils placed over the A-K region. The magnetic field is generated by a 180 mm-I.D. backing coil in the vacuum diode and a 130 mm-I.D. air-core extraction magnet which center is located 100 mm from the cathode. The axial magnetic field strength in the centre of the extraction magnet is about 0.8 kG. To arrive at the final diode design, the computer 2D codes EGUN [3] and SAM were used. The simulation geometry (SAM) is shown in Fig.4. The numerical calculation gave the following results: the rms beam radius is 2 cm, the rms emittance is 80 cm mrad and the current density on the cathode surface is about 30 A/cm^2. The simple variant of the cathode assembly without a focus electrode was also calculated by EGUN code. The simulation geometry is shown in Fig.5. This is a basic variant of the cathode assembly with the parameters similar to the previous variant.

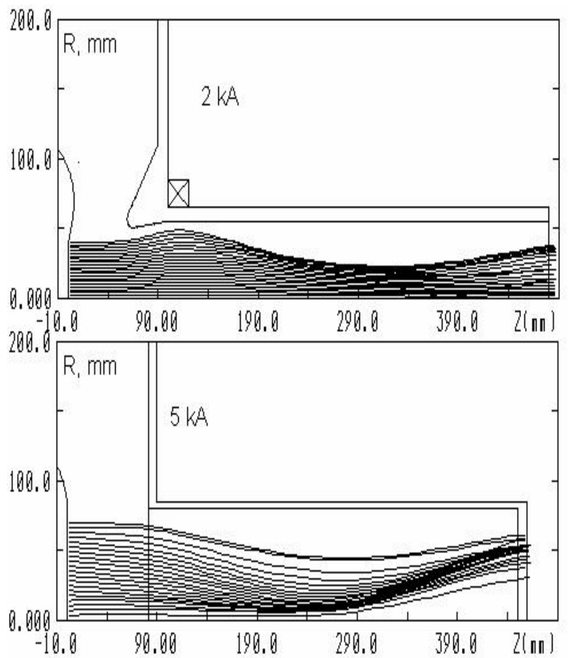

Figure: 4 The simulation geometry.

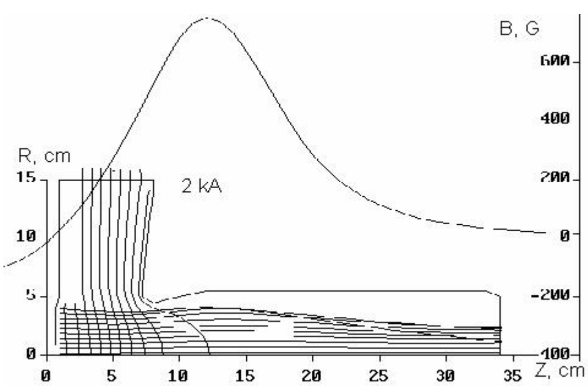

Figure: 5 A basic variant of the cathode assembly.

In the second mode the 140 mm diam replacement velvet cathode without a focus electrode is used. In this case the anode is planar and consists of a grid. The anode grid is fabricated by stretching 0.08 mm thick tungsten wire on a pattern of slots cut into the supporting rings. The width of the openings between the wires is less than 5mm. The diode configuration showing the electron trajectories is indicated in Fig.4.

1.4 Ancillary arrangements

To measure the parameters of the electron beam and induction cells in the exploitation mode the following monitors are used: a capacitive (E - dot) monitor located inside the vacuum tank versus the cathode assembly, Rogowski coil on the cathode stalk, a resistive probe and an electron collector, where electrons are stopped, and Rogowski coils in the induction cells.

The vacuum in the vacuum tank of the electron gun is ensured by 500 l/s turbomolecular pump.

2 CONCLUSION

We suppose to have the injector in operation within the current year. The generator is expected to be built and installed in coming months. Now we have all the induction cells made.

REFERENCES

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