A Chopped Electron Beam Driver for H-Type Cavities

S. Setzer *, T. Weiland, Darmstadt University of Technology
U. Ratzinger, GSI Darmstadt; S. Minaev, ITEP Moscow

Abstract

The acceleration of heavy ions with H-type structures is usually powered by tube driven rf transmitters. These are limited to about 1 MW in pulsed operation and at frequencies above 200 MHz. This paper reports about an rf amplifier development, which should allow to improve the rf power level as well as the reliability significantly. An electron beam is directly coupled with one girder of an H-type structure by a two gap-array. In contrast to the bunch formation in klystrons a chopper technique is applied to get reasonable mechanical dimensions for the amplifier at frequencies below 400 MHz. A high perveance beam from a pierce-type electron gun is chopped in two steps by passage along the magnetic field of a solenoid and superposition of a transverse rf electric field (two harmonics) and of a transverse electrostatic field, respectively. The deflected particles are dumped in a depressed collector while the penetrating electron bunch may be post-accelerated additionally before entering the H-type cavity. MAFIA-PIC-code simulations have demonstrated the efficiency of the suggested chopper array and have allowed to improve the design of this key element.

1 INTRODUCTION

The frequency range between 350 MHz and about 20 GHz is dominated by klystron amplifiers, where an electron beam is bunched by a longitudinal velocity modulation and by passing a subsequent drift length. The bunches drive the output cavity and the remaining energy is deposited in a beam dump. At an operating frequency of 350 MHz the length of such a device is about 5 m (i.e. TH2089 by Thomson). This is mainly due to the needed drift space. For lower frequencies conventional tube amplifiers and IOTs are used which can not compete with klystrons concerning output power, efficiency and maintenance. We will discuss a new concept of electron bunch formation making the main advantages of the klystron principle available at lower frequencies. The goal is to design an amplifier covering the frequency range between 100 MHz and 400 MHz and providing up to 10 MW rf power for 1 ms pulse duration at a repetition rate of typically 10 Hz.

2 BASIC CONCEPT

A high perveance electron beam with a radius of 5 mm is generated by a pierce type gun. Instead of applying a longitudinal velocity modulation, transverse rf as well as static electric fields are used to deflect about 80% of the continuous beam during one rf period to a depressed beam dump. The applied electric forces and the static magnetic field needed for compensating the space charge expansion of the beam (“Brillouin-Flow”) results in the so called “E×B-Drift” depicted in Fig. 1. The deflection process itself takes place in two separate stages, a rf driven stage and a dc driven postdeflector [1]. Fig. 2 shows the rf voltage applied to the first stage by an external generator. Its essential property is a plateau at 0 V recurring with the desired operating frequency f. These plateaus contain about 20% of the beam and correspond to 70° in units of the operating frequency f. The appropriate rf voltage results from superposing two sinusoidal signals with the frequencies f/2 and 5f/2 and at an amplitude ratio of 5:1. The postdeflector operates on dc potential. To simplify the whole device

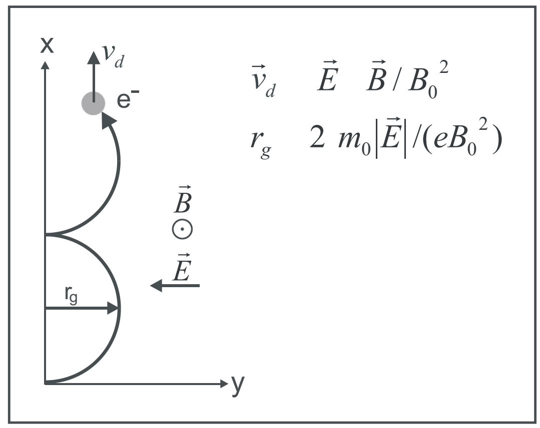

Figure 1: E×B-drift of an electron as a result of perpendicular electric and magnetic fields

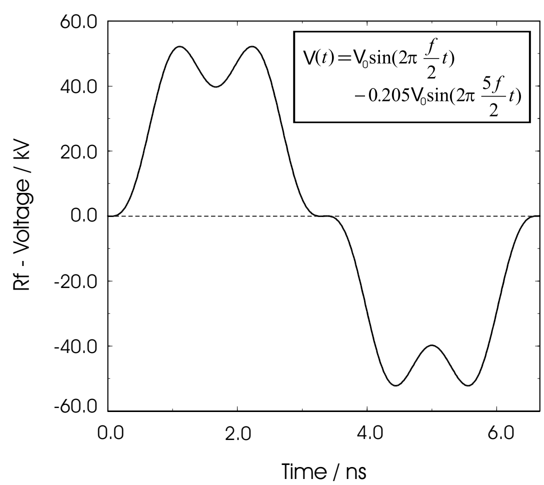

Figure 2: RF voltage applied to the first deflecting stage

* Member of the Graduiertenkolleg (DFG GK-GRK 410/1)

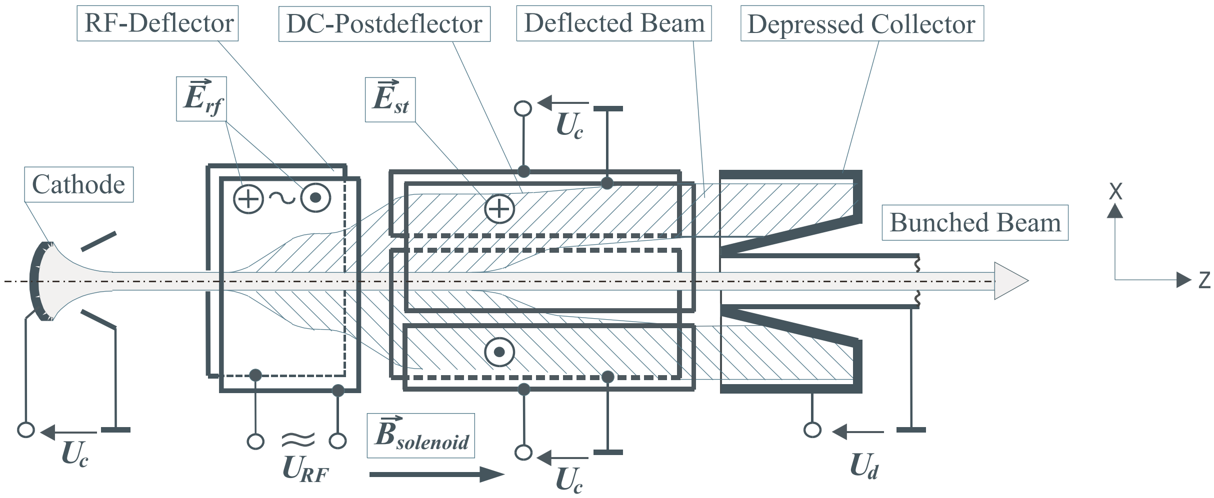

Figure 3: General setup of the deflecting device

the same voltage needed for the gun may be used at modest beam energies. The dc stage is added to increase the beam deflection initiated by the rf part. The beam separation caused by the two stages has to be large enough to avoid beam tube damages and to allow for an efficient energy recovery by charging the electron gun mainly via the depressed collector (like in case of e^- coolers used in storage rings). A setup of the deflecting device is shown in Fig. 3. The bunched beam leaving the deflector on axis may be post-accelerated up to about 300 kV before injection into the output cavity. This could be a one gap cavity analogous to klystrons. Fig. 4 shows an accelerator relevant case, where the ion accelerator cavity of the IH-type is directly driven by the electron beam. The coupling is done by two gaps [2].

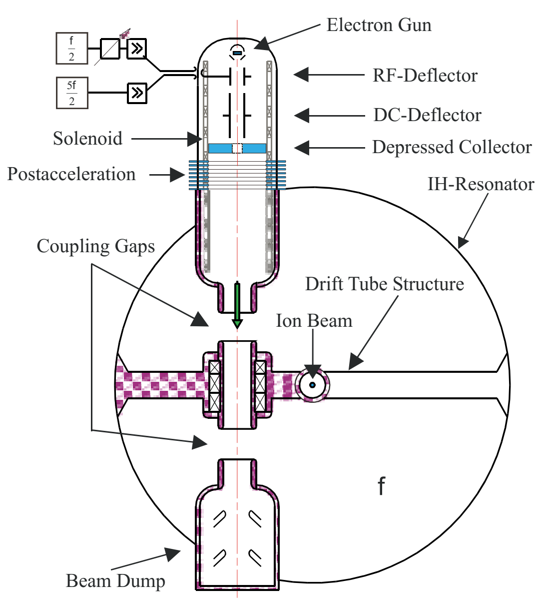

Figure 4: IH-type accelerating structure directly driven by a bunched electron beam

3 SIMULATION RESULTS

To demonstrate the feasibility of the proposed bunch formation method, detailed simulations for a 300 MHz amplifier using the PIC code MAFIA TS3 [3] have been performed. In one example the initial radius of the 40 kV, 40 A beam entering the deflector is 5 mm, the magnetic flux density needed for confining the beam is 80 mT. The rf deflector has a length of 55 mm, the dc stage is 150 mm long. Fig. 5 shows the electron density distribution right behind the rf deflector. The hatched area corresponds to a beam width of ±6.3 mm. As mentioned above, the

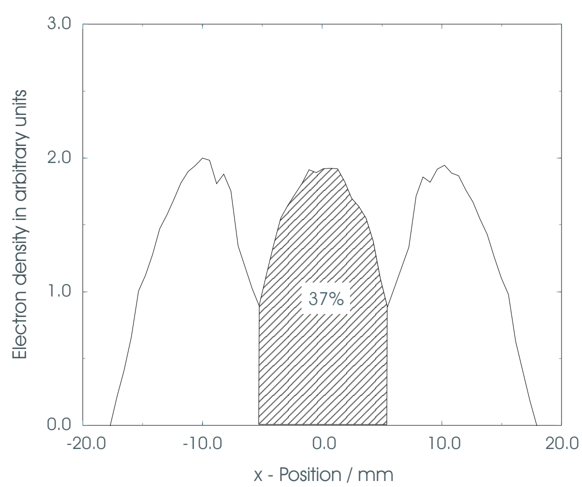

Figure 5: Electron density distribution behind the rf deflector

deflection achieved in the first stage is not sufficient. The situation improves drastically while the beam passes the dc deflector. The resulting electron density is depicted in Fig. 6. The longitudinal electron density of the created bunches leaving the deflector within defined windows in x-direction is shown in Fig. 7.

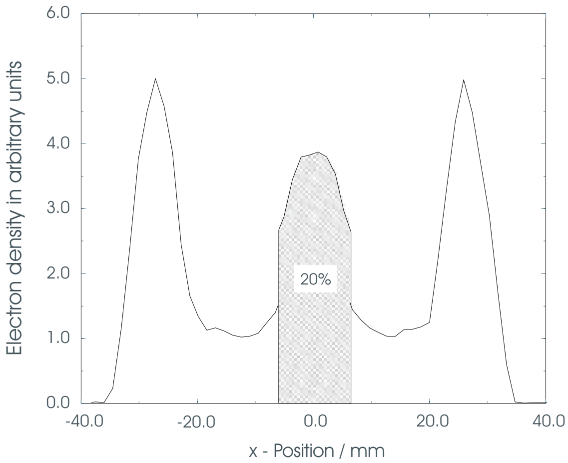

Figure 6: Electron density distribution behind the dc deflector

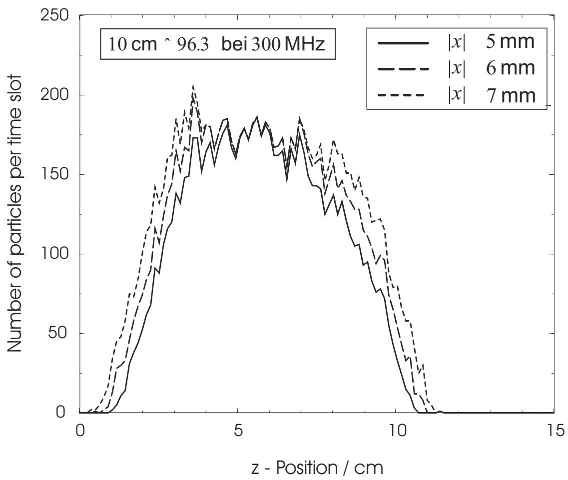

Figure 7: Longitudinal bunch shape of the generated bunches for three different transverse sizes

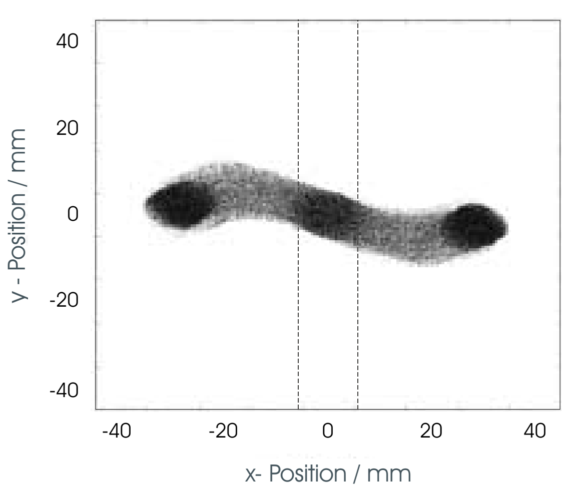

Figure 8: Projection of all particles in the x-y plane behind the beam deflector

The fluctuation of the curves is a result of the limited number of macroparticles used for the simulation. Fig. 8 shows the projection in the x-y plane of all particles which are contained within one rf period behind the dc deflector. The width of the bunches which will be used for driving the resonator is about 13 mm in x direction and about 11 mm in y direction, respectively. It also gives a good impression about the needed collector entrance geometry. In a next step the collector will be developed based on this particle distribution.

4 CONCLUSIONS AND OUTLOOK

The simulation results demonstrate that it is possible to use the proposed deflecting setup for bunch formation at frequencies between 100 MHz and 400 MHz. A device using a 40 A beam with a post-acceleration of the bunches to 300 keV would be able to provide up to 2 MW to the output cavity. These parameters where chosen as starting point for the investigations. This scheme can also be adopted to a 100 A beam. Such a device would deliver an rf output power of up to 6 MW. To simplify the technical realization it is investigated at present whether the beam deflector can be operated at ground potential even in the case of high beam energies. In a next step, a technical realization of the proposed rf amplifier is envisaged at IAP, University Frankfurt.

5 REFERENCES

[1] S. Setzer, T. Weiland, U. Ratzinger, S. Minaev, “A RF Chopped Electron Beam Driver for H-Type Cavities”, GSI Scientific Report 1999, GSI-2000-1, p.194

[2] U. Ratzinger, Doctoral thesis, TU München, 1986, p.53

[3] MAFIA, CST-GmbH, Büdinger Straße 2a, D-64289 Darmstadt