MULTI-DIMENSIONAL RF SOURCES DESIGN*

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Abstract

Vacuum electronic devices, such as rf sources for accelerator applications, must provide high rf power with high efficiency. To achieve these requirements, multi-beam klystron and sheet-beam klystron devices have been developed. Multi-beam klystrons, at high frequency employ separate output cavities; hence they have the disadvantage that combining all the rf pulses, generated by all the beams, is challenging. Sheet-beam klystrons have problems with instabilities and with space charge forces that makes the beam not naturally confined. We are proposing an alternative approach that reduces space charge problems, by adopting geometries in which the space charge forces are naturally balanced. An example is when the electron beam is generated by a central source (well) and the electron motion corresponds to the natural expansion of the electron cloud (three-dimensional device). In this paper we will present the design and challenges of a bi-dimensional rf source, a cylindrical klystron, composed by concentric pancake resonant cavities. In this case, space charge forces are naturally balanced in the azimuthal direction.

INTRODUCTION

High power klystrons devices are based on multi-beam and sheet beam devices. Multi-beam klystrons [1] at high frequencies are made with individual klystrons, where the rf power is combined afterwards. Combining all the rf pulses with the right rf-phase is challenging. Sheet beam klystrons [2] have problems with instabilities. The aspect ratio of the beam makes the space charge forces not naturally balanced, generating instabilities. We want to explore new geometries where the space charge effects are reduced. To achieve this goal we started the klystron design by exploring configurations where the electrons are allowed to propagate according to them natural expansion. Fig. 1 shows the three-dimensional electron motion, where the electrons are generated from a central source (cathode) and allowed to propagate in the three-dimensional space. As a consequence of this free three-dimensional beam motion, the transverse space charge forces are fully balanced.

As a first design step, we considered the design of a klystron with a two-dimensional electron beam motion, called radial klystron [3, 4, 5, 6]. The radial klystron is a cylindrical device where the electrons are generated by a cylindrical gun and propagate in the radial direction (See Fig. 2(a)) generating a pancake electron stream. The

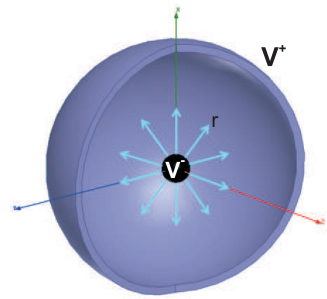

Figure 1: Three-dimensional natural expansion of electrons.

space charge space charge forces are naturally balanced in the azimuthal direction. The cavities are concentric coaxial resonators working with the fundamental mode TEM_1 (See Fig. 2(b)). The coaxial resonators are endowed with

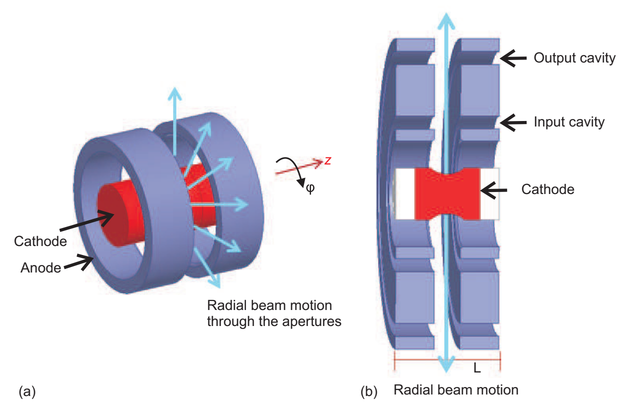

Figure 2: Cylindrical gun with two-dimensional electrons expansion (a), Radial klystron with two coaxial resonators (b).

beampipe apertures that allow the pancake electron stream to propagate.

This paper presents the design of a radial klystron. The electron beam interaction with the cavities has been analyzed with an in-house developed particle tracking software. The maximum efficiency of the output cavity has been evaluated with a Dirac delta beam test. The multi cavity klystron has been designed. Afterwards we designed the radial electron gun and the beam transport, focused with PPM system.

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KLYSTRON DESIGN

We designed a X-band radial klystron, with frequency f = 11.424 GHz. The efficiency must be at least 60% with an anodic voltage V_a = 30 kV, which allows to use a smaller modulator, and anodic current I_a = 40 A.

The design workflow is the following:

1. Optimize the output cavity with one particle beam (delta function);

2. Design of the whole klystron with input, buncher and output cavities;

3. Design the radial gun and the PPM beam focusing system.

Optimization of the output cavity

The first step in the klystron design is to optimize the output cavity geometry with a perfectly bunched beam (Delta function). The design has been carried out with an in-house developed FEM simulation code, which calculates the eigensolutions of the cavity fields. The interaction of the electron beam with the cavity fields is achieved with a particle tracking software, in-house developed as well. It takes into account the beam loading. It evaluates the steady-state complex power balance between the power extracted from the beam, the power dissipated in the cavity walls and power transmitted through the output waveguide. With this tool it is possible to evaluate the voltage induced in each cavity, and the beam dynamics. It is possible to evaluate the efficiency of the output cavity, given the electron bunch parameters. The cavity surfaces have been rounded to minimize the losses. The optimized output cavity geometry, working with the TEM_1 mode, is shown in Fig. 3(a), while Fig. 3(b) shows the cavity efficiency in function of the β coupling factor. The shunt impedance of

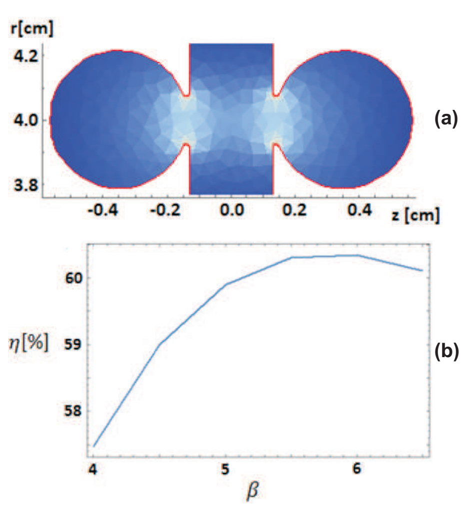

Figure 3: Optimized output geometry (a), efficiency vs. coupling, with one particle beam test (b).

this coaxial resonator has a "1/r" dependence, where "r" is the distance of the coaxial resonator with respect to the central axis. The shunt impedance radial dependence is shown in Fig. 4. In order to obtain high efficiencies, we

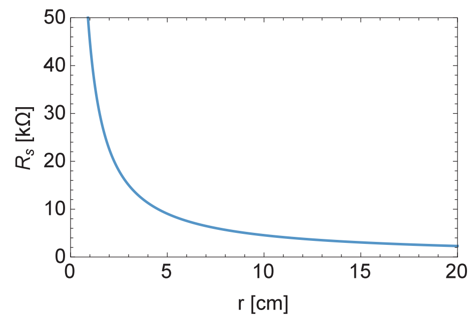

Figure 4: Dependence of the shunt impedance on the position "r" of the output cavity.

need high shunt impedance in the output cavity. From the plot of Fig. 4, we need to place the output cavity at a low radius, close to the center, so that shunt impedance is high. For space reasons, all the other cavities (input and bunching) are outside, at bigger radii. Therefore we will use a klystron where the electrons travel in an inward direction, from the outside towards the center. This direction is opposite of Fig. 2. The output cavity was fixed at 4 cm, in order to allow a space for the central collector.

Design the input and buncher cavities

After optimizing the output cavity, the whole klystron has been designed. We used the in-house developed FEM simulation and particle tracking software. As a first design step, the ballistic optimization has been performed, supposing negligible the space-charge effects. In order to have high efficiency, four cavities are needed. Precisely, an input cavity, a bunching cavity and two output cavities. The power generated by the two output cavities will be combined afterwards. The schematic of the klystron is depicted in Fig. 5, where the couplings of the output cavities are: β_1 = 8.7 and β_2 = 8.5. All cavities are tuned at the frequency f = 11.424 GHz.

The sum of the two output cavities efficiencies is 60 % (η_1 = 40% and η_1 = 20 %), producing 30 dB gain with 600 W of input power. Details on the current harmonic growth are reported in [7].

Electron gun design

Since the electrons are travelling along the inward direction, we plan to build and to verify the beam transport system. We designed a Pierce electron gun with PPM (periodic permanent magnet) focusing [8], shown in Fig. 6. We modulated the period length and the magnetization of the magnets according to [3], where the B-field must vary as: $B(r) \propto \sqrt{r}$ and the PPM period linearly with r, as the electron beam travels towards the center. We used 11 magnets, where the maximum B-field of the magnets is 0.33 T and the minimum period is 6 mm. We performed the simu-

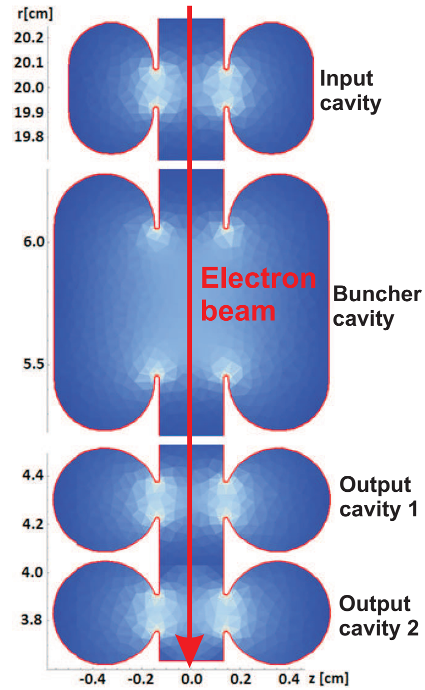

Figure 5: Klystron design. For drawing reasons, the input, bunching and the output cavities are separated.

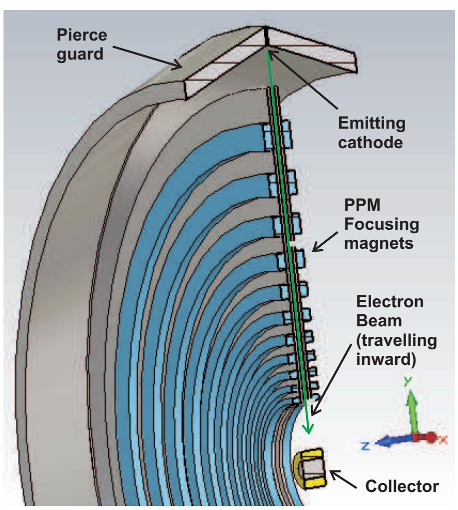

Figure 6: Pierce electron gun with PPM focusing.

lations with CST studio [9], achieving 100% of beam transport along the drift tube. Fig. 7 shows the phase space plot of the particles positions. The coordinate "r" is the distance from the central "z" axis (reference system of Fig. 4). We have good transport since the beam never intersects the drift tube walls.

CONCLUSIONS

Radial klystrons are rf sources where the electron beam travels along the radial dimension. The azimuthal space-charge forces are balanced. They are alternatives to sheet-beam klystrons. The electron beam is generated by a cylindrical gun and it interacts with cavities (the input, the bunching cavities and the output cavity) that are made with concentric coaxial resonators. The optimization of the output cavity has been carried out by using a perfectly bunched beam. The whole klystron has been designed with the ballistic approximation. A total of four cavities has been used, providing 60% of efficiency at the frequency of 11.424 GHz. We shown the design of the electron gun with PPM focusing. We performed the tracking simulations with CST studio and we achieved 100% of beam transport along the drift tube.

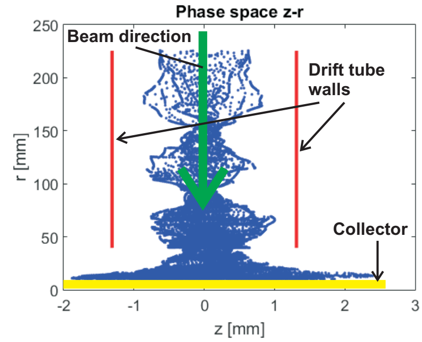

Figure 7: Phase space of the particle positions in the plane z-r. There is 100% of beam transport along the drift tube.

ACKNOWLEDGMENT

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