MULTIPLE BEAM GUNS FOR HIGH POWER RF APPLICATIONS

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Abstract

The U.S. Department of Energy is funding development of multiple beam electron guns for high power RF sources. The advantage of multiple beam devices is that the operating voltage can be significantly reduced from that required for a single beam. In a multiple beam device, the beam power is divided into a multiplicity of smaller beams that traverse the RF circuit in individual beam tunnels. This dramatically reduces the space charge forces that drive the beam voltage requirement. The reduced operating voltage significantly reduces the cost of the power supply system, improves efficiency, reduces the device length, lower the magnetic field required for confinement, reduces radiations hazards, and increases the bandwidth. This paper describes an eight beam gun designed to produce 100 MW of beam power for a multiple beam klystron.

INTRODUCTION

Multiple beam guns (MBGs) are finding increased application in different types of microwave tubes. The advantages of having MBGs in a microwave tube, for example, in a klystron (MBK), is a decrease of beam voltage, reduced power densities and lower voltage gradients. Another advantage is increased bandwidth and lower x-radiation production. A detailed description of multiple beam devices and their advantages and applications was recently described in a publication by from the Naval Research Laboratory[1].

At present most MBKs use Brillouin focusing where the cathode is shielded from the magnetic focusing field. This type focusing is seldom used in the single beam, high power klystrons due to inferior beam transmission as compared to the confined flow focusing. Presently available MBK tubes typically have beam transmission of 90% or less. In fact most of them have transmission less than 80%, some even operate with less than 70% transmission. In comparison most high power, single beam klystrons have transmission around 99%.

MBKs with confined flow magnetic focusing will be capable of much higher values of RF power. The objective of this program is to demonstrate confined flow focusing in a multiple beam gun applicable to a 50 MW klystron at X-Band.

The main objective of this program is to design multiple beam guns with confined flow focused beams off axis on a radius determined by the RF cavity design. This is not a trivial task, because in this type of gun, the magnetic flux reaching the cathode is no longer symmetric with the cathode center. If left uncompensated, the radial divergence in the magnetic field will distort the shape and size of the beam and prevent adequate transmission.

COMPUTER SIMULATION TOOLS FOR 2-D AND 3D INVESTIGATIONS

The geometry of multiple beam guns requires advanced 3D simulation tools. A number of the required tools were developed during the course of this research. The program extensively utilized a number of commercial 2D and 3D computer codes, including EGUN, TRAK, Maxwell 2D and 3D, and MAFIA. Principle code for modeling the electron beam optics was TOPAZ, a computer code developed by Valentin Ivanov at Stanford Linear Accelerator Center. Additional information on this code is available from another paper being presented at this conference[2].

MULTIPLE BEAM GUN DESIGN

The beam requirements were determined for a multiple beam klystron producing 50 MW of RF power at 11.424 GHz. The initial circuit design was performed in parallel by scientists in the United States and Russia. Both organizations arrived at the same circuit design and beam specifications, providing high confidence that the beam specifications were correct. Subsequently, U.S. Department of Energy funding was provided to perform more research on the klystron relevant to the gun produced here, and that program successfully produced a 50 MW klystron design. That design is also being presented at this conference[2].

Each of the eight beams is designed to provide approximately 12.5 MW of beam power with an operating voltage of 175 kV. The beam voltage was chosen to be consistent with currently available solid-state power supplies. The radial position of the electron beams is at the approximate position of the third radial maximum of the TM_{03} mode at 11.424 GHz. This is 6.3 cm from the central axis of the gun.

Initially, a 12.5 MW electron gun was designed on axis to determine the geometrical requirements for generating the correct perveance and beam size. The magnitude and shape of the magnetic field was also determined for the

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on-axis gun and was used as the goal configuration for the off-axis guns.

Following design of the 12.5 MW gun on axis, the geometry was shifted 6.3 cm from the axis and duplicated to generate eight electrons guns about the primary axis of the gun. At this point, 3D simulation was required to design electrical and magnetic structures to generate the goal magnetic field about the local axis of each of the eight beams. It was necessary to simulate all beams in order to properly account for the additional space charge in the cathode-anode regions and the self magnetic fields of all the beams. Principle design tools were MAFIA, to generate the electrical and magnetic fields and TOPAZ to propagate the electron beams through the device geometry. Figure 1 shows the predicted performance for one of the eight electron beams.

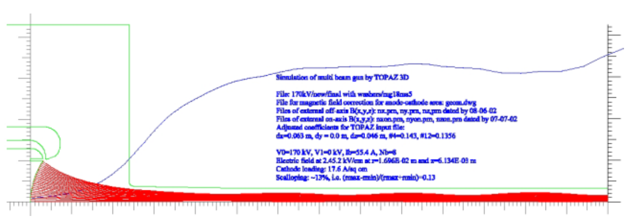

Figure 1. TOPAZ simulation of one of the eight multiple beams

The principle challenge in designing confined flow multiple beam guns is controlling the magnetic field in the cathode-anode region. Without correction, the field will radially diverge as it exits from the beam openings in the magnetic polepiece. During the program, iron structures were designed to surround the individual cathodes and force the magnetic field to be symmetric about the local axis of each cathode.

Another challenge is to design the electric and magnetic field structure to counteract any tendency of the electron beams to spiral about the primary axis of the gun. It was determined that azimuthal correction to the field structure was required to generate beams that did not spiral. Figure 2 shows the iron structure used to provide the required field correction.

Figure 2. Field shaping iron in cathode-anode region

The gun is designed for testing in a special beam analyzer, also being developed on this program. The beam analyzer will allow testing of the gun at reduced voltage and current so that the current profile of an electron beam can be measured at various axial positions. Consequently, the prototype gun will be tested at approximately 12 kV. Stepper motors will transport a Faraday probe across the electron beam to generate a transverse profile of the beam current. The probes can be located at several axial positions to measure beam scallop and detect any spiraling motion.

A solid model of the prototype electron gun is shown in Figure 3. Because the gun will operate a significantly reduced voltage from the design value, it can be operated without a high temperature bake. The gun will be connected to vacuum pumps through conflat flanges and will be demountable from the beam analyzer. The gun is designed so that critical surfaces can be readjusted, and the gun retested. It should be noted that the computer tools used for the design are, themselves, untested against actual measurements. Not only will the test results characterize the operation of the gun, they will also be used to validate the accuracy of the computer tools. This will facilitate design of additional 3D devices and development of more advanced multiple beam guns.

Figure 3. Solid model of eight beam electron gun

ELECTRON GUN AND PROGRAM STATUS

The design for the electron gun is complete and construction is underway. Figure 4 shows the eight electron guns mounted in the high voltage assembly. All parts for the gun are in stock, and the assembly should be completed in June 2002.

A beam analyzer is being constructed to measure the performance of the gun. A current probe will measure the transverse current profile at various distances from the cathode. This will allow determination of the beam size, scallop, current profile, and any spiraling of the beams. The beam analyzer is scheduled for completion at the end of June. The power supply system is already in place and the control software is almost complete.

Following successful completion of the development of this gun, a doubly convergent gun will be designed. That gun will allow an increase in the total beam power with a decrease in the cathode current emission density.

Figure 4. Eight beam, multiple beam gun under construction

SUMMARY

A multiple beam gun is currently being constructed to provide approximately 100 MW of beam power for an X-Band klystron. The gun consists of eight cathodes and field shaping iron to provide a high quality beam without spiraling. If successful, the gun will be capable of powering a 50 MW klystron with a beam voltage of less than 200 kV.

ACKNOWLEDGEMENT

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