MECHANICAL DESIGN OF A RF ELECTRON GUN*

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Abstract

Brookhaven National Laboratory is building an Accelerator Test Facility at which we plan to study laser acceleration of electrons, inverse free electron lasers and the production of X-rays by non-linear Compton scattering. The facility contains an electron gun, linac, lasers and ancillary systems which will enable the production of 6 ps duration pulses of 50–100 MeV electrons.

The electron source is an one and one half cell RF Electron gun which utilizes either a thermionic or photoemissive cathode to produce 5 MeV electrons.

This paper discusses how gun mechanical design considerations such as material, vacuum maintenance, surface finish, fabrication methods, cavity tuning, and cathode replacement were reconciled to arrive at the final design.

Introduction

The BNL electron gun was based on a paper by Frazer et al[1] which describes a gun design utilizing a photocathode at one end of a RF cavity. Many disciplines are involved in developing an electron gun design utilizing RF power and a photoemmisive cathode. This paper focuses primarily on the mechanical engineering aspects of the design.

The BNL gun cavity dimensions were calculated using the programs SUPERFISH[2] and MAFIA[3]. Additionally, a brass model of the gun was employed to confirm the calculated cell dimensions and also to develop an arrangement for coupling the wave guide to the gun.

The gun (see fig. 1) consists of a one and one half cell side coupled accelerator structure fabricated from copper and stainless steel. The central gun body is a monolithic cylinder bored from each end with closures EB welded in place. RF power is supplied to both cells via a section of standard vacuum S-Band wave guide fabricated so that it can be EB welded to the gun body. Table 1 summarizes the electron gun physical characteristics.

Mechanical Design

Initially a thermionic cathode will be used as an electron source. The design allows alternate photocathodes to be substituted. A RF choke joint is used between the cathode holder and the cavity surface to eliminate the need for an electrical joint at this location.

Cavity frequency tuning will be accomplished by iterative assembly, measurement and machining of the central section to achieve the correct frequency. Tuner loops in each cell allow fine tuning after total assembly. RF monitoring is provided by means of small coupling loops in each cell (see Fig. 2).

Table 1. RF Electron Gun Characteristics[4]

Cell Diameter, mm	83.08
Full Cell Length, mm	32.58
No. of Cells	1-1/2
Aperture, mm	20
Operating Frequency, GHz	2.856
Body Outside Diameter, mm	127
Max. Surface Electric Field, MV/m	118
Cavity Peak Power	5.3 MW

Temperature control is achieved by water passageways bored longitudinally in the central body and water jackets on the end caps.

Material

The material selected for the gun body is oxygen free copper (alloy C10100 certified to ASTM F68-82 Class II or better). This material was selected because of its excellent thermal and electrical characteristics. Additionally, the very low incidence of copper oxide inclusions would enhance internal surface finish subsequent to hydrogen brazing. Since we decided to electron beam weld rather than braze, the benefit of the high purity is some what lessened. However surface finish of the cavity is important because at high electrical surface fields micro protrusions and surface discontinuities lead to electrical breakdown.[5]

The high thermal conductivity of copper helps to maintain a uniform gun temperature for dimensional stability. Heating from RF losses in the gun are relatively low because of the short pulse time and may be approximated as follows:

$$Q_L = 5.3 \times 10^6 \text{ W} \times 6 \times 10^{-6} \frac{\text{s}}{\text{pulse}} \times 6 \frac{\text{pulse}}{\text{s}} = 191 \text{ W}$$

The sensitivity of the cavity resonant frequency to temperature change can be approximated by:

$$\frac{\Delta f}{\Delta T} = -0.05 \frac{\text{MHz}}{°\text{C}}$$ [6]

The acceptable amount of resonant frequency variation for the gun is 3–5 kHz.[7] This results in the requirement to maintain gun temperature variations to within 0.1°C.

Vacuum

It is very desirable to maintain good vacuum in the gun interior to minimize "poisoning" of the photocathode. To achieve the goal of 10^{-10} Torr two pumps are used. The first is a 30 l/s ion pump attached to a port off the gun wave guide and the second is a small 8 l/s pump which is attached to a second port near the RF choke joint.

The interior surfaces of the gun will be conditioned by Electropolishing. This electrochemical process involves immersing the surfaces in an acid bath with a anodic current applied to them. The result is microleveling of any protrusions leaving a bright glossy surface, typically having a 2–5 microinches finish.[8] In addition to the vacuum benefits of this surface treatment, the resistance to electrical breakdown under high electrical fields is improved. Since electropolishing removes material, it will be carried out prior to tuning.

An initial bakeout at 300°C is planned to remove any water vapor. Also, the initial gun operation with a thermionic cathode, will result in further beneficial conditioning.

Fabrication

The gun is assembled from four major subassemblies: the body, the cathode end, the beam exit and the waveguide subassembly.

Electron beam welding has been used extensively in the assembly of the gun for several reasons. Hydrogen brazing is not presently done at Brookhaven, moreover, the commercial brazing facilities in the region are relatively unfamiliar with UHV component brazing especially one with exacting dimensional requirements. Additionally, the design would require the brazing to be

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Table 2. Frequency Variation

Cell Dimension	Dimension Tolerance, mm	Frequency Variation, MHz
Diameter	+/-.013	+/- .45
Full Cell Length	-0/+0.03	+0/-2.63
Half Cell Length	-0/+0.03	+0/-5.63

done in several stages, increasing the opportunity for thermal distortions and possible porosity at interior surfaces from the reaction of hydrogen with inclusions.[9]

Cell dimensional tolerances strongly influence the resonant frequency. An approximation of this dependence is that the frequency change is inversely proportional to the cell diameter and length change.[7,8] Based on this Table 2 gives the calculated variations due to cell dimensional tolerances. These numbers are consistent with data taken from the model gun.

In order to accomplish the initial tuning, the gun body and ends will be assembled and clamped. Frequency measurements will be made and the body will be machined. Several iterations are expected to achieve the final dimensions. The closures will be clamped and EB welded to the body along with the waveguide assembly and other appendages. After final assembly, the fine tuning loops have a range of up to a 2 MHz frequency increase.

Cathode

As previously mentioned, the cathodes are interchangeable. Both the thermionic cathode and the photocathode are electric beam welded into a copper cathode plug. Access to the plug is through a 4.5 in diameter "Conflat" flange at the rear of the gun. (see fig.1). The plug is held in contact with the gun body by a spring which is compressed as the flange as made up.

The thermionic cathode is made from a Machlett ML-6442 triode. After welding to the cathode plug, the anode end is removed in a nitrogen atmosphere and the assembly is installed in the electron gun.

Presently, we are planning on using a yttrium photocathode which appears to be more resistant to "poisoning". The design of the access to the cathode is such that with a some minimal additional design, cathodes can be changed while maintaining vacuum in the gun.

Conclusions

The design and fabrication of any RF accelerating device equipment has always been a difficult and demanding task. The existence of unique operational conditions can make the use of alternative fabrication techniques a viable method of producing these devices.

Acknowledgments

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References

[1] J.S. Fraser et al., "Photocathodes in Accelerator Applications," Proc. of the 1987 IEEE Particle Accelerator Conf., ed. by E.R. Lindstrom and IL.S. Taylor (Washington,D.C., Mar. 16-19, 1987) pp. 1705-1709.

[2] K. Halbach and R.F. Holsinger, Particle Accelerators **7** (1976) pp. 213.

[3] R. Klatt et al., "MAFIA, A Three Dimensional Electromagnetic CAD System for Magnets, R.F. Structures and Wake-Field Calculations," 1986 Linear Accelerator Conference Proceedings, SLAC 303.

[4] K. Batchelor et al., "Development of a High Brightness Electron Gun for the Accelerator Test Facility at Brookhaven National Laboratory."

[5] J.W. Wang and G.A. Loew, "Progress Report on New Breakdown Studies in An S-Band Structure at SLAC," Proceedings of the 1987 IEEE Particle Accelerator Conference (March 16-19, 1987) pp. 1854-1856.

[6] R.B. Neal et al., "The Stanford Two Mile Linear Accelerator," (1968), W.A. Benjamim, Publisher.

[7] K. Batchelor, Private Communication.

[8] ASM Metals Handbook, 8th Edition, Volume II, American Society For Metals, pp. 484-488.

[9] Los Alamos Memorandum to J.E. Stoval from R.D. Reiswig Dated 24 March 1987.

Figures

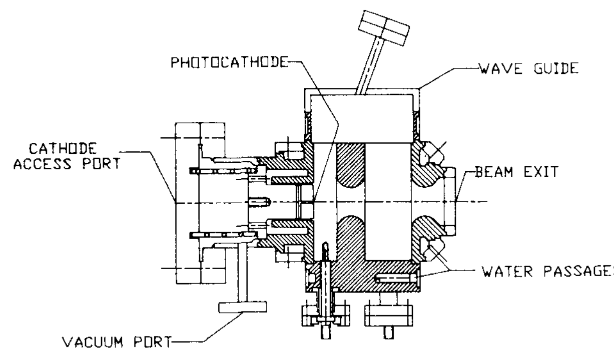

FIGURE 1 RF ELECTRON GUN SECTION

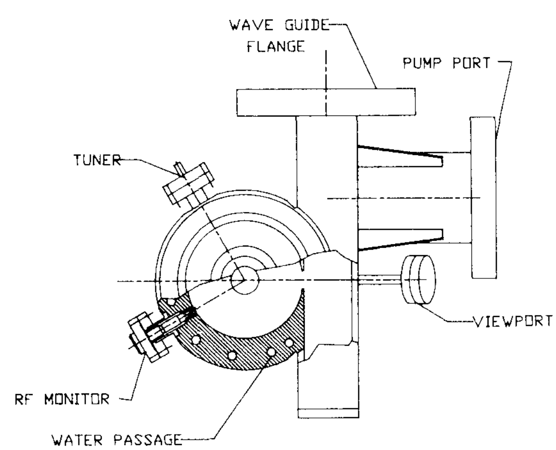

FIGURE 2 RF ELECTRON GUN END VIEW