JLAB HIGH EFFICIENCY KLYSTRON BASELINE DESIGN FOR 12 GEV UPGRADE*

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Abstract

A computer design of a 13.5 kW, 1497 MHz, CW type, 55% efficiency, 0.8 μP beam perveance, ~40 dB gain, 5-cavity klystron has been developed for the JLAB 12GeV Upgrade project. The design uses TRICOMP codes to simulate the gun, modulating anode section, solenoid focus channel and beam dump. The klystron tube was designed by JPNDISK (1D) code initially and then optimized by MASK (2D) code for the baseline parameters. All of these codes have been bench marked by JLAB 5 kW operational klystrons. The details of scaling laws, design parameters and the simulation results are presented.

INTRODUCTION

The CEBAF energy upgrade from 6GeV to 12GeV at JLab requires that the klystron power (CW type) to be 13kW for the new high gradient superconducting cavity [1]. A new product or design of a high efficiency (>50%) klystron had been specified. In addition to the bidding process with the klystron tube industry and the SBIR development program, we have independently designed this klystron using integrated computer tools. Before proceeding with the new design, we have used these tools to bench-mark our operating 5kW klystron. A possible beam interception in the gun to mod-anode section was found [2]. This problem caused potted ceramic insulators thermal runaway and finally damaged klystrons in the CEBAF machine.

We used TRICOMP (2D) [3] package to design the gun section from cathode to modulation anode, and the focusing channel from anode to beam dump. For the klystron tube design, we used small signal analysis first to get initial design parameters. We then put them into the large signal 1D JPNDISK code to get parameter optimization. These parameters were optimized further by the 2D MASK code to get the transverse space-charge effects. From MASK's result, we finally designed the klystron dimensions with Superfish [4]. We found that a 5-gap klystron is the minimum length structure and can be used as our baseline for a low cost design. In Table 1, we list the design specifications and what we have achieved in our preliminary design. Operation at 1dB below saturation and with a wide bandwidth was based on the CEBAF superconducting cavity's control experience. It normally contradicts a high efficiency tube design. A new low-level RF control system will be designed to work in conjunction with this new klystron.

Table 1: Specification and achieved design parameters.

Parameters	Specification	Achieved in Design
Frequency	1497MHz	1497MHz
Saturated power	16.4kW	15kW
Operating power	13kW	13.5kW
Saturated gain	40dB	41.8dB
Bandwidth	3dB>6MHz or 1dB>5MHz	3dB: 5.7MHz; 1dB: 3.8MHz
Efficiency	>50%	55%
Beam voltage	<30kV	16kV
Beam current	NS	1.6A
Gradient in gun	<75kV/cm	48kV/cm
Gradient in cavity	<300kV/cm	48.3kV/cm
Magnetic field	<2kGauss	1.7kGauss

DESIGN SURVEY AND SCALING LAWS

To achieve a high efficiency klystron design, the first approach is to lower the beam perveance and to use longer drifting tubes. We have summarized two scaling laws from our achieved data and a survey from the production catalogs of two major klystron vendors.

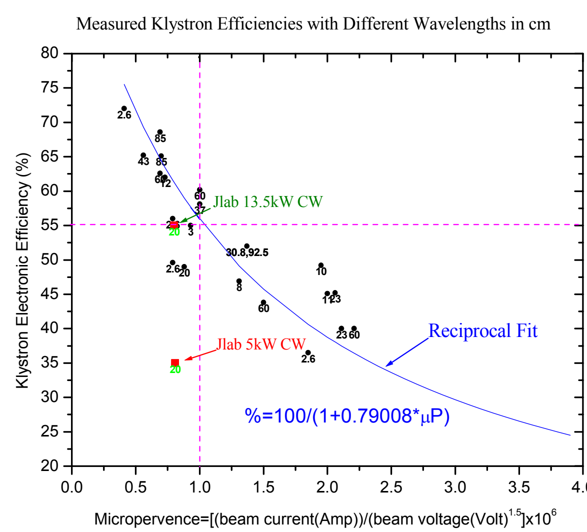

Figure 1: Klystron efficiency vs beam preveance.

Figure 1 shows that a 0.8 μP beam perveance design can achieve our 50% efficiency goal. The efficiency of current JLab 5kW klystron is well below the fitting curve. By the same fitting curve, we did a comparison between the vendor 1 and vendor 2. We found the vendor 1

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follows the curve but the vendor 2 is below (Figure 2). Based on the data from vendor 1, the linear fittings can be obtained for different type of klystrons. Each type has a different slope. The PPM has a more effective focusing than the solenoid. The CW klystron normally has a larger beam dump than the pulsed type. The total length does not depend on the operating frequency because it only affects the transverse dimension. The klystron tube length is normally proportional to the plasma wavelength. And the plasma wavelength is $\lambda_p \propto V^{1/4}/j^{1/2}$ (V is the beam voltage and j is the current density) which is space charge and bunching effect related.

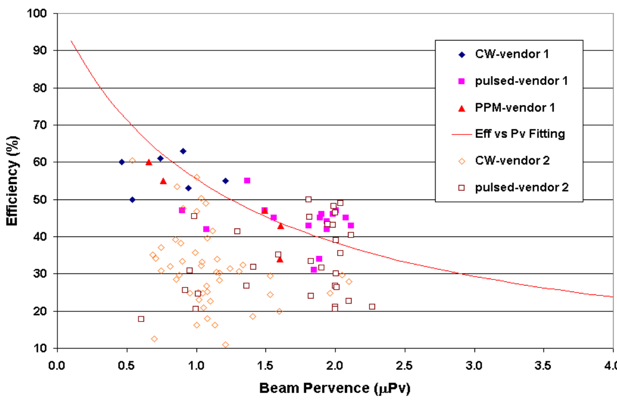

Figure 2: Efficiency vs. perveance to compare between vendor 1 and vendor 2.

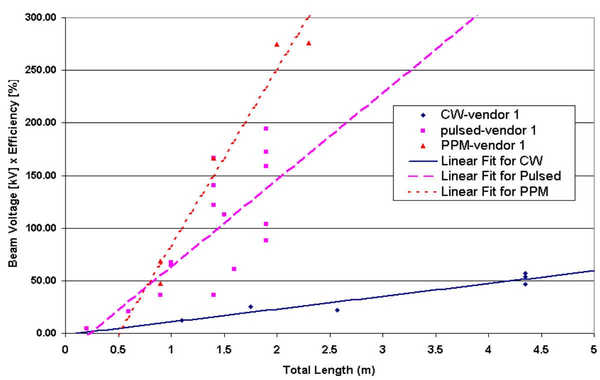

Figure 3: Beam voltage × efficiency vs. total length.

PIERCE GUN AND BEAM DUMP DESIGN

The cathode is a thermionic dispenser type. The current density is 0.4A/cm^2, low enough for long-life operation. It works at the temperature-limited current emission with the cathode voltage of –16kV and the beam current of 1.6A. The maximum static electric field at the focus electrode is 48kV/cm. With a solenoid field ramping from 300 G at the cathode surface to a flat top of 1700 G at the anode entrance, the beam compresses down to a 5.6mm radius with a scallop amplitude of ~9%. The area compression ratio is 18:1 (Figure 4). With a -4kV mod-anode voltage, the maximum field between the mod-anode cylinder and the ground tube is 24.8kV/cm. The ceramic insulator is going to be air-cooled without potting. With a falloff of 370gauss/cm of the solenoid field, the full power of the beam can be uniformly dumped.

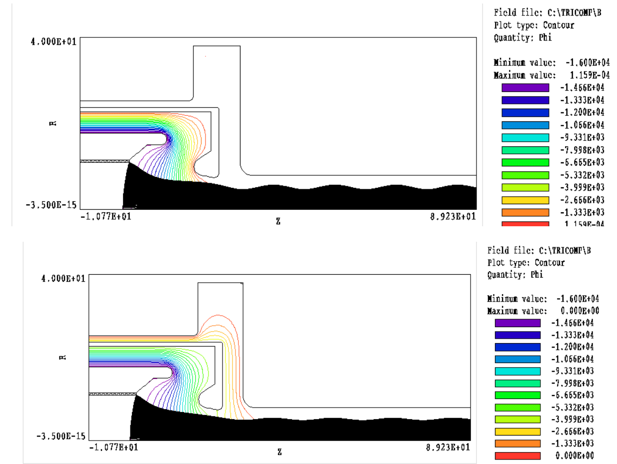

Figure 4: TRICOMP simulations in gun section. The potential at the cathode is –16kV; the mod-anode is 0kV in top plot and -4kV in bottom plot.

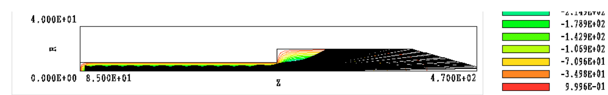

Figure 5: TRICOMP simulation in tube and beam dump.

KLYSTRON TUBE DESIGN

The tube is a 5-gap, single output gap cavity with a long drift from 3rd to 4th gap. The beam pipe radius is 8mm. The beam-filling factor is 70%. The input power for a saturated output is 1.18W. The electronic efficiency is 55% and the kinetic efficiency is 57.2% No second harmonic cavity was used on this design. Table 2 lists the design parameters. The "detune" is the detuned cavity frequency minus operating frequency.

Table 2: Tube design parameters optimized by MASK.

Cavity No.	1	2	3	4	5
Qexts	400	2000	2000	2000	260
R/Qs (Ω)	95.0	95.0	95.0	95.0	95.0
Gaps (mm)	7.5	7.5	7.5	7.5	7.0
Drift pos. (mm)	0	40	78	160	200
Detune (MHz)	0.2	2.7	8.0	10.0	-1.0

We note that there is a small difference between the 1D JPNDISK code and 2D MASK code in the optimized parameters. In Figures 6~9, we show the JPNDISK output plots. Figure 10 is one of MASK output plots.

KLYSTRON CAVITY DESIGN

Since the required cavity's R/Q is relative low, we adopted a pillbox reentrant shape cavity to achieve the desired value. The cavity resonant frequencies can be obtained by adjusting the cavities outer radii. Figure 11 shows the detail dimension calculated by Superfish. The maximum electric field (48.3kV/cm) is at the output gap. The tuners will be radial button type and on all cavities. The input coupler will be inductive loop type. The output waveguide will be side coupling and bent to interleave with the solenoid pole plate. A detail 3D MAFIA design needs to be developed.

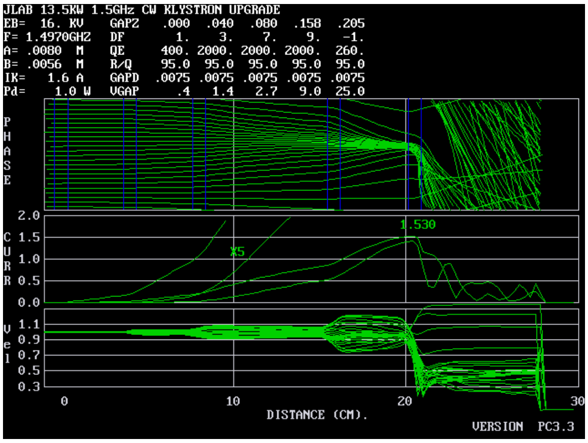

Figure 6: The JPNDIS simulation. Up to down: input parameters, Applegate plot, RF current verse z, velocity spread verse z.

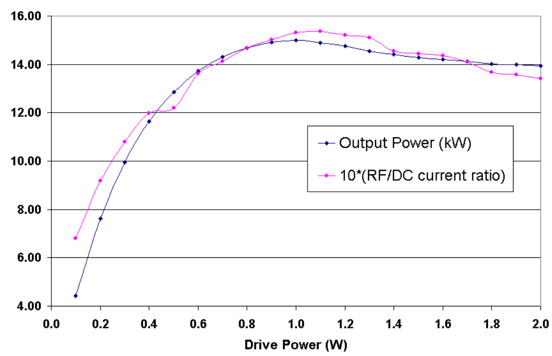

Figure 7: JPNDISK calculated output power verse input.

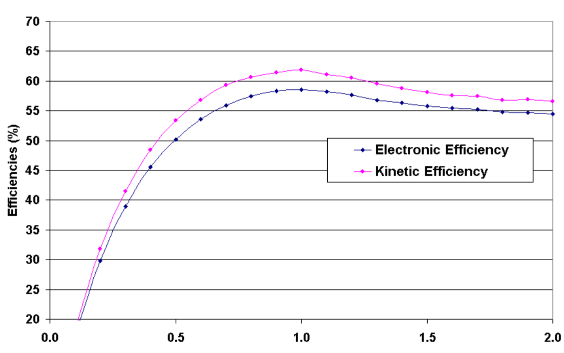

Figure 8: JPNDISK calculated efficiency vs drive power.

SUMMARY

The initial computer design to a 13.5kW RF power and 55% efficiency of a CW klystron for the JLab 12GeV Upgrade has been achieved. Although it is not a best design yet, it should be complementary to a parallel SBIR design [5]. We need to do further on the component designs, mechanical and thermal dynamic simulations. A prototyping program or an adjoining venture with SBIR is needed in near future.

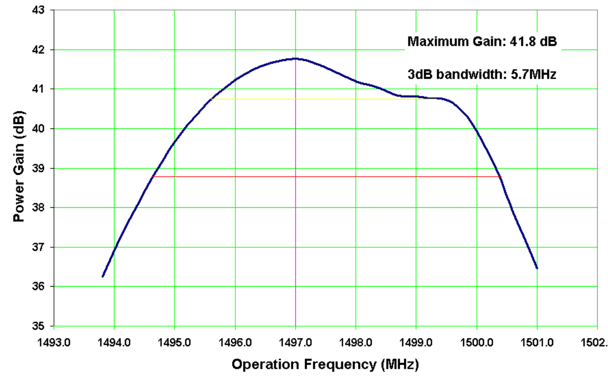

Figure 9: JPNDISK calculated gain and bandwidth.

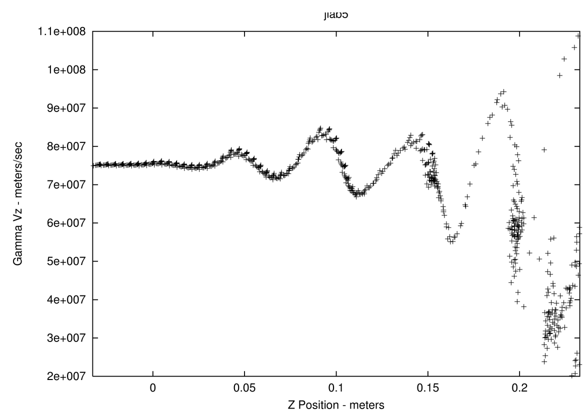

Figure 10: MASK output, transverse velocity verse z position. The gap positions are shown in Table 2.

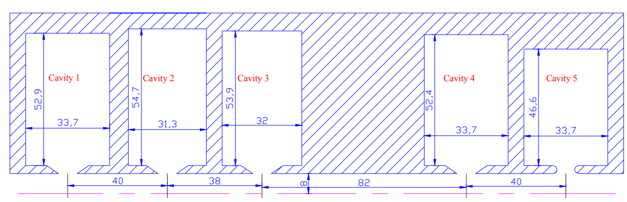

Figure 11: Klystron cavities designed by Superfish. All dimensions are in mm.

ACKNOWLEDGMENT

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