DESIGN OF A HIGH EFFICIENCY 1 MW CW KLYSTRON AT 700 MHz FOR LOW ENERGY DEMONSTRATOR ACCELERATOR

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Abstract

A 1 MW CW 700 MHz high efficiency klystron has been designed, built and tested for the Low Energy Demonstrator Accelerator (LEDA) project at the Los Alamos National Laboratory. Computer simulation tools were used to design various aspects of the klystron including the electron gun, electromagnet, cavities and RF output structure; the results will be presented along with the design concepts. Important features of the design included a collector with full beam power dissipation capability and stable operation into a load with a VSWR of 1.2:1. A 1-D klystron simulation code was used to optimise the tuning pattern. A comparison of the results against the measured data will be given.

1 INTRODUCTION

A new 1 MW 700 MHz high efficiency klystron, the K3510L (see figure 1), has been developed at EEV for the coupled cavity drift tube linac (CCDTL) stage of the low energy demonstrator accelerator (LEDA) at the LANL. Computer modelling techniques were extensively applied to the electronic and mechanical problems of the tube design and contributed to the success of serial number one.

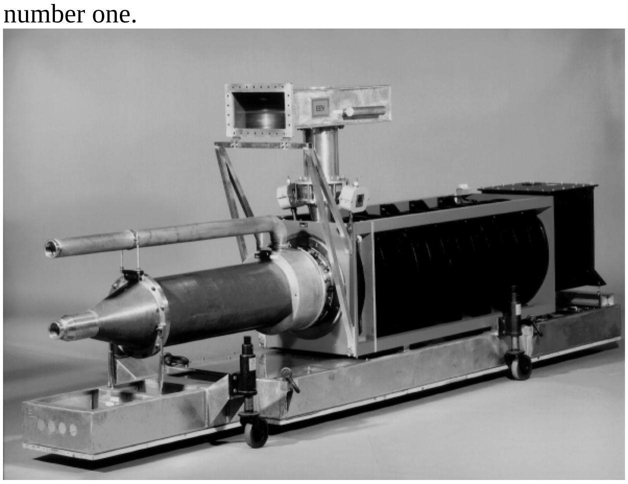


Figure 1: K3510L 1 MW CW 700 MHz Klystron

The key design parameters for the device are as follows:

Centre Frequency	700 MHz
Bandwidth -1dB	∀0.7 MHz
Rated Output Power	1000 kW
Test Power	1100 kW
Beam Voltage (max)	95 kV
Beam Current (max)	16.5 A
Efficiency	65 %
Gain	40 dB
Collector Dissipation	full beam power

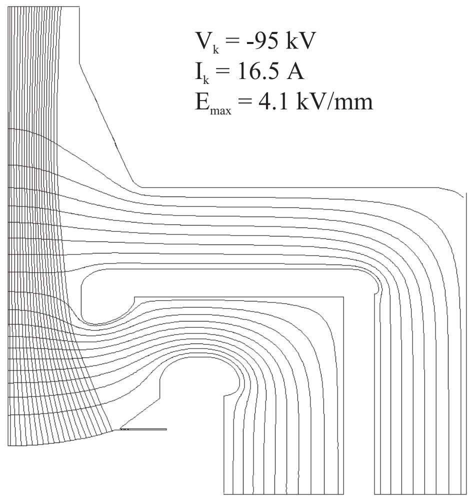
In addition the klystron must be free from sideband oscillations through all phases of a 1.2:1 load impedance.

2 DESIGN ASPECTS

2.1 Electron Beam Design

The electron gun and solenoid were designed using an electromagnetic modelling software Opera2D (from Vector Fields Ltd). The electron gun, a modified >Pierce= type shown in figure 2, generates a laminar beam with low ripple ($\Delta r/r_o < 0.15$). In addition, conservative values for cathode current density ($< 0.58 Acm^{-2}$) and peak operating electric field ($< 4.1\ kVmm^{-1}$) contribute to a long life and reliable design.

The magnetic field strength was chosen to be twice the Brilluoiun field (B_B=157 Gauss) over the input stages of the tube rising to three times B_B at the output end, in order to counteract the increased space charge forces in the heavily bunched beam.



K3510L equipotentials

Figure 2: Electron Gun Simulation

2.2 Collector Design

An efficient collector design is required not only to deal with the high power density at the position of first beam impact, but also at the collector end under low perveance or gas focused conditions. Conventional forced water cooling (axially oriented cooling fins) is limited to power densities of the order of 0.5 $kWcm^{-2}$ and the difficulty in maintaining efficient cooling at the collector end without adding complexity to the fin design. For these reasons an existing mixed phase cooled (transverse cooling fins) collector design was adopted, albeit extended in length. Analysis of the electron beam spread in this collector using Opera2D gave a maximum intercepted power density of 650 Wcm^{-2} under full beam conditions (see figure 3). Suitable dimensioning of the sub cooling channel gave an operating safety factor of two times the peak heat flux at the rated coolant flow[2].

2.3 RF Section and Tuning

The klystron is a six cavity design (five fundamental and one harmonic) stagger tuned for high efficiency[1], the passband being formed predominantly by the input cavity. The second cavity is effectively >de-Q-d= by a combination of beam loading (transit angle of 1 radian) and lossy cavity walls in order to help suppress sideband oscillations[1]. An externally coupled load was therefore not required.

The cavity structures were designed using the KCC MICRO-STRIPES code, which is based on the Transmission-Line Modelling method, with a view to optimising the R/Q (for cylindrical geometry). This was in order to allow the inductively tuned intermediate cavities to be set to higher frequencies for efficiency purposes. The computed R/Q of 140 was subsequently verified using a perturbation measurement.

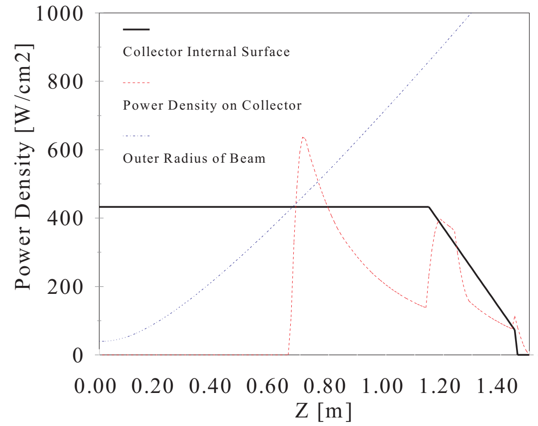


Figure 3: Simulation of Electron Beam Spread into the Collector

2.4 RF Output

The output from the klystron is fed to WR1500 waveguide via a coaxial ceramic RF window. The RF match of the window, the coax to waveguide T-bar transition and the combination of the two was optimised using MICRO-STRIPES. Particular attention was paid to the avoidance of coaxial TE_{11} resonances in the transition region. This resulted in a T-bar width only slighter larger than the coaxial inner diameter. The diameters of the coaxial line between the transition and the RF window were chosen to be a compromise between RF losses and the coaxial TE_{11} mode cut-off frequency. The line length was therefore long in order to attenuate sufficiently the evanescent coaxial TE_{11} mode fields in the transition region before they reached the RF window. The ceramic window was studied as part of a 700 MHz RF window assembly, with particular attention paid to the mechanical stresses due to RF heating. The structure was modelled using MAFIA to generate an RF heating profile across the ceramic. This data was scaled and then transferred to a model constructed on ANSYS (which included cooling air flow) to generate a temperature profile and subsequently the mechanical stress induced in the ceramic. The analysis showed that the peak stresses were a factor of four lower than the failure stress of the ceramic used (260 MPa [3]).

3 LARGE SIGNAL SIMULATION

The klystron tuning pattern was quickly optimised using the 1D code JPNDisk. It was found that with drift lengths and the cavity detuning almost directly scaled from the 350MHz 1.3MW klystron (K3513) the tube gain and efficiency could be readily met. The cold (i.e. beam off) Q factor of the second cavity was shown to have very little effect, over a range of practical values, on the predicted performance. Figure 4 shows a plot of the >electron= disk phases for the final simulated design.

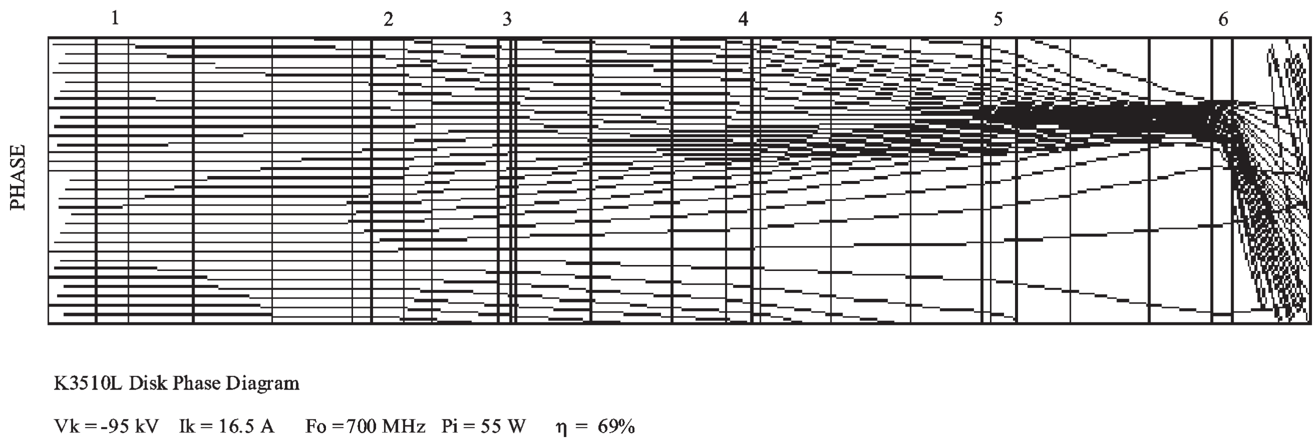


Figure 4: K3510L 'Electron' disk phase diagram

4 MEASUREMENT RESULTS

The klystron has been built and tested, meeting all performance criteria. The key points are listed below:

Output Power	1010 kW
Bandwidth -1dB	∀1.2 MHz
Beam Voltage	95 kV
Beam Current	16.3 A
Efficiency	65.2 %
Gain	40.8 dB
Collector Dissipation	full beam power

At the test power of 1.1 MW the efficiency was slightly higher at 66.1%. The VSWR tolerance criteria were tested using a PTFE plate with a mismatch of 1.2:1 varied through $\lambda_G/2$. During this test the tube demonstrated excellent stability with low modulating anode current (<0.5 mA). The computed efficiency of 69 % was in reasonable agreement with the measured result i.e. a comparable over-estimation of efficiency as on other EEV klystrons that have been modelled. Figure 5 shows a comparison of the computed and measured transfer characteristics.

5 CONCLUSIONS

A new 1 MW 700 MHz klystron has been designed and demonstrated to meet to meet rigorous operating conditions. Fundamental to the successful design has been the application of computer aided engineering tools in conjunction with experience gained over eight years of super power klystron production.

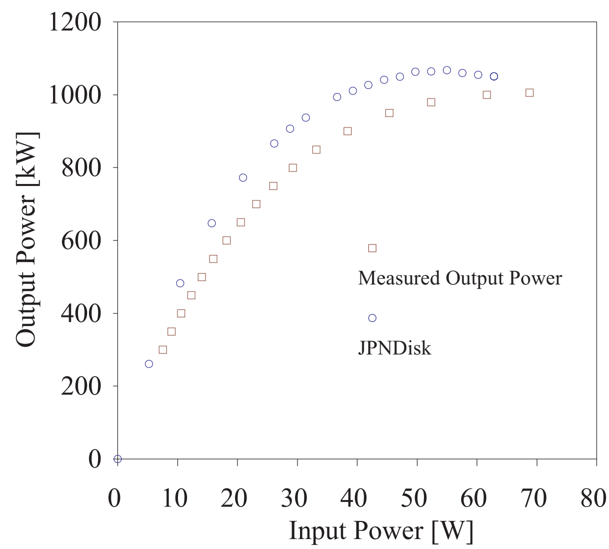


Figure 5: Comparison of Measured and Computed Transfer Characteristic
NB Input power is equivalent amplifier output

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