1.2 MW KLYSTRON FOR ASYMMETRIC STORAGE RING B FACTORY

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Abstract

A cw klystron operating at 476 MHz has been developed jointly by SLAC and Varian Associates. The unique set of characteristics of this tube were strongly guided by requirements of the fast feedback necessary to prevent oscillations of the storage ring beams caused by the detuned accelerating cavity. This requires a combination of bandwidth and short group delay within the klystron. The RF feedback stabilization scheme also requires amplitude modulation making it necessary to operate the klystron about 10% below saturation. Performance specifications and initial operating results are presented.

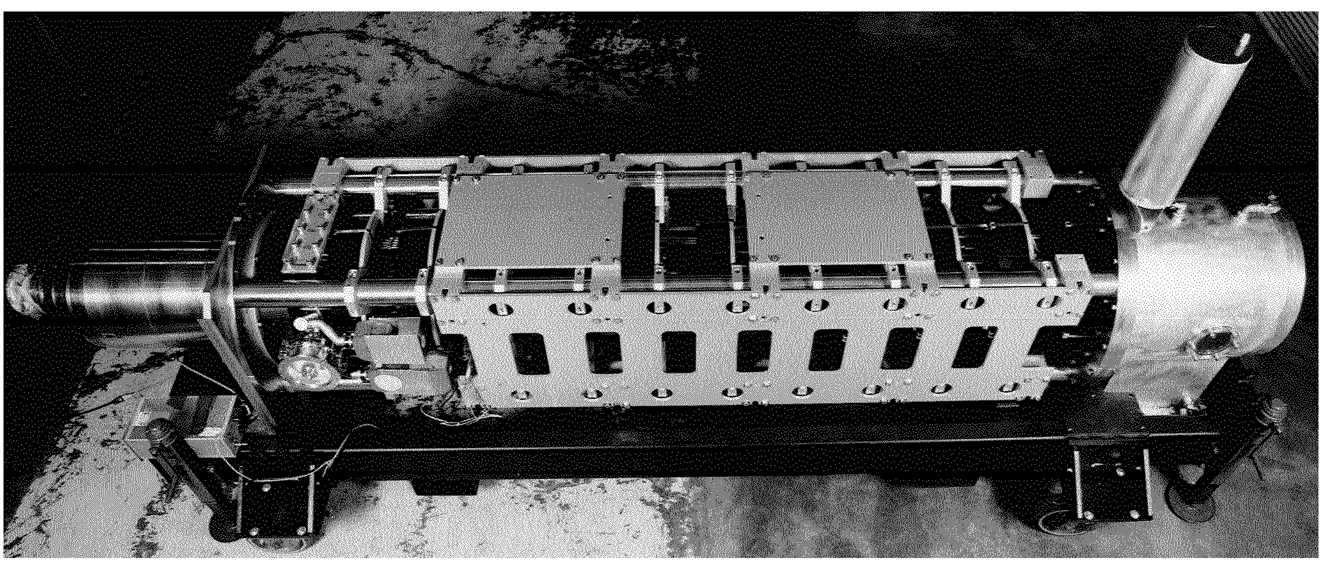
I. INTRODUCTION

SLAC and Varian have joined efforts under a Cooperative Research and Development Agreement (CRADA) to develop and test a new UHF super power klystron as a prototype 476 MHz RF source for the Asymmetric Storage Ring B Factory under construction at SLAC. This klystron was originally designed to produce 1.6 MW CW saturated to be operated at 90 KV, 27 amperes. After the klystron development was well underway, some of the requirements were relaxed as a result of further study in the accelerator physics aspects of the machine. As a result, the klystron will be operated conservatively at 83.5 KV and would deliver 1.2 MW if saturated. The klystron will be operated 10% below saturation and must be able to respond to fast feedback correction in both amplitude and phase in order to damp accelerating cavity oscillations induced by high current storage ring beams. This feedback scheme requires the klystron to have very short group delay ($d\phi/d\omega$) and wide bandwidth. When this development effort began neither of these features were available off the shelf in commercial tubes of similar power and frequency such as those used at LEP and TRISTAN storage rings.

A multistage depressed collector, designed by Varian was very seriously pursued because much of the efficiency that is given up running underdriven is recovered. The operating cost savings would have been substantial but the manufacturing risks and additional upfront costs were considered too great to continue along the MSDC path. The "headroom" needed for amplitude modulation was reduced from 25% to 10%. The design parameters for this tube are listed in the table below.

DESIGN PARAMETERS

Operating Frequency (MHz)	476
Output Power at Saturation (KW)	1200
Operating Point Below Saturation (KW)	1100
Beam Voltage (KV)	83.5
Beam Current (A)	24.1
Efficiency (%)	>60
Saturated Gain (dB)	>43
1 dB Bandwidth (MHz)	±3.0
Group Delay at ±0.5 MHz (nanosec.)	100



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II. ELECTRICAL DESIGN

The Varian electron gun design has a peak cathode loading of 0.31 A/cm^2 and a maximum surface gradient of 50 KV/cm. Computer simulation predicts a beam diameter of 4.5 cm with a 5.8% scallop in a 7 cm tunnel diameter. The mechanical design was borrowed from the SLAC 5045 gun which allows adjustment of the radial and axial position of the cathode and focus electrode with respect to the anode. The alignment must be preserved while operating horizontally. It is primarily radiatively cooled to the anode housing. An internal copper web conducts heat from the region of the focus electrode adjacent to the cathode out to the large outside diameter where it is radiated away to the anode housing.

The 7 cavity interaction region designed by Varian was optimized for 90 KV to provide the required combination of bandwidth and low group delay without compromising gain or efficiency. As mentioned earlier it will be operated at 83.5 KV corresponding to a 3% lower average beam velocity. The staggered tuning arrangement of the first three cavities is expected to provide about 6 MHz of 1 dB bandwidth and about 150 nanoseconds of group delay across that bandwidth as shown in figures 1 and 2 respectively. A cavity tuned slightly below the second harmonic of the operating frequency followed by two inductively tuned cavities provide a highly optimized bunch passing through the output resonator. The second harmonic cavity plays an important role in achieving a low electron density in the antibunch region as the beam passes through the output gap[1][2].

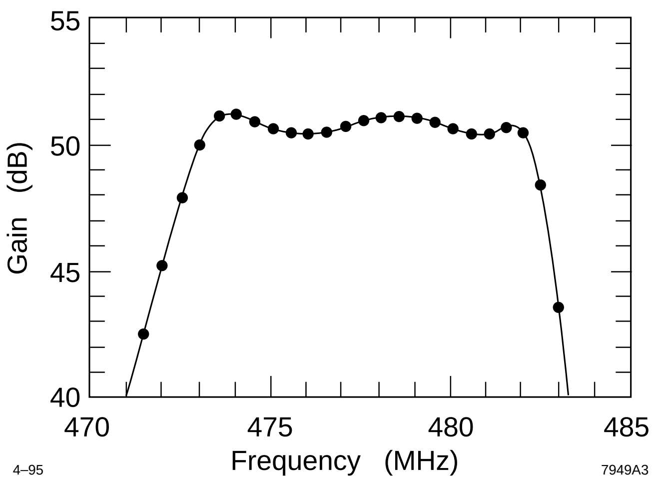

Figure 1. Predicted Small-Signal Gain versus Frequency Response at 90 KV

The output coupling loop is designed to give an external Q of 36 for the output cavity. This value is slightly below that which gives optimum efficiency but assures that the lowest velocity electrons will not cause regeneration. The entire output coupling circuit was modeled using MAFIA. The measured results for both resonant frequency and external Q agreed with the simulation to better than 0.1%

Both 1D and 2D PIC codes developed at Varian were used in the interaction design simulation. Figure 3 shows the predicted saturation curves using each of the simulation codes. Similar results were obtained using JPNDISK and CONDOR. The 2-D simulations have historically shown good agreement with measured results while the 1-D results need to be derated by about 10%.

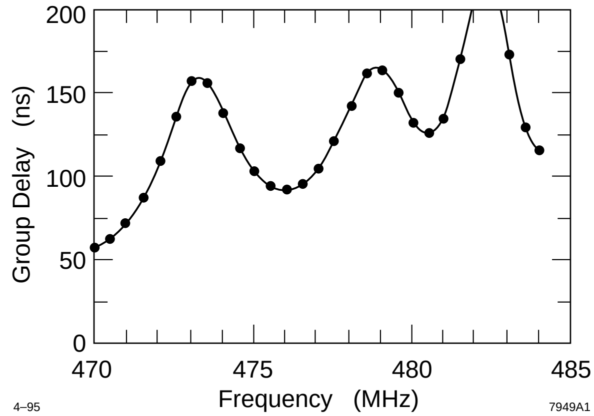

Figure 2. Predicted Group Delay versus Frequency at 90 KV

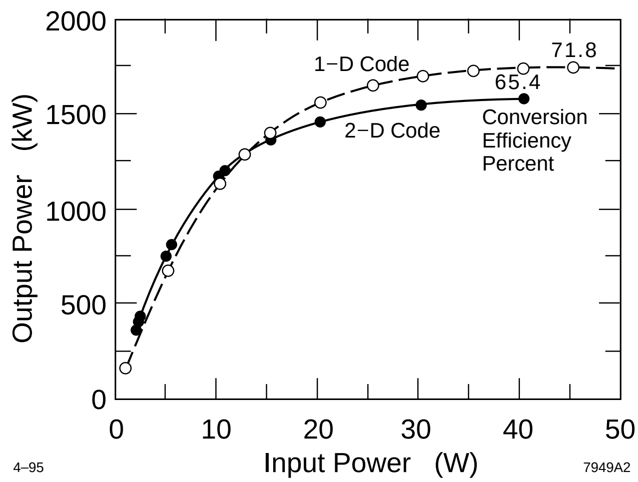

Figure 3. Predicted Output Power versus Drive at 90 KV

III. MECHANICAL DESIGN

All the cavities except the output cavity are made from stainless steel cylinders and end plates which are copper plated for good RF conductivity. The output cavity, owing to its high wall losses, has OFE copper walls with an outer stainless steel reinforcing structure. Each cavity except the output has a tuning mechanism whereby a series of differential screws are driven by chains to move one of the reentrant cavity noses relative to the other. The cavities with this tuning arrangement have a flexible copper end wall to allow the movement of the cavity nose. The tuning rate for the cavities are such that the ±.025 inch adjustment range gives a frequency shift of ±1.8 MHz for the fundamental cavities and approximately twice that for the second harmonic cavity. The tuners may be used while the tube is operating. Each cavity except the output cavity has its own diagnostic RF monitor loop. The noses of all cavities except the prepenultimate and the second harmonic were coated with TiN to help suppress multipactor. In addition the input cavity drive loop, the output coupling loop and the vacuum side of the output window were also coated for the same reason. The output coupling loop and all cavities are water cooled to stabilize their operating temperature and hence frequency. All drift tubes are also water cooled as protection against electron beam interception.

The limited bakeout station clearance required optimization of the collector design to minimize the tube length. The interior is contoured to have nearly constant flux for highest surface cooling efficiency. The large inside diameter of the collector necessitated a departure from standard collector designs where there is an inner collector with milled cooling channels and an outer, separable water jacket. This is to avoid excessively high stresses in the collector wall due to the pressure of the cooling water. This construction technique allows optimal design of the cooling channels and wall thickness for best cooling performance. In addition, one-piece construction allows the monitoring of beam deposition by measuring temperatures on the outer jacket.

The coaxial output window has matching choke hubs in 50 ohm 6.125 " diameter coax line. Air cooling of the inner conductor and window face is accomplished by ducting air (approximately 50 scfm dry air) through the T-bar coupler into the inner conductor and across the window through jets at the bottom of the inner conductor matching choke. The air exits to the atmosphere via holes at the bottom of the outer conductor choke hub. The inner and outer conductors are water cooled on the vacuum side only.

The T-bar coax to WR2100 waveguide transition was preferred over the doorknob type because of its good bandwidth and the configuration allows access to the inner conductor for blowing air and placing window temperature monitoring thermocouples. It also allows compliant coupling between the inner conductor and the T-bar to prevent excessive mechanical loading on the output window. A compliant membrane is also designed into the vacuum side output coax center conductor.

The magnet consists of twelve individual convection cooled coils that are airspaced with approximately a 45% fill factor to allow access to the tube body for tuning. The magnet return path is formed by four symmetrically placed four inch diameter steel pipes that run the length of the klystron between the gun end and collector end polepieces. The magnet return path also serves to support and space the coils as well as to support the klystron in the horizontal position. Rails attached to the klystron body engage support shoes on each magnet coil support allowing transverse support and longitudinal freedom to allow differential thermal expansion between the klystron body and the magnet support structure.

The support structure under the magnet frame has both heavy duty casters and jack screws so that the entire assembly including gun oil tank can be rolled into place in the final operating position in the B-Factory klystron housing.

IV. TEST RESULTS

The klystron went into test in mid-February and processed cleanly up to 60 KV. At this point the 2.6 MW dc power supply failed, putting an end to publishing any test results in time for this conference. The measured RF output power the lower voltages showed good agreement with simulation predictions where the efficiency is expected to be low. As of this printing the klystron is awaiting the repair of the power supply so that testing may continue. There is every indication that the klystron will meet all of the performance predictions.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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