DESIGN AND OPERATION OF A HIGH POWER L-BAND MULTIPLE BEAM KLYSTRON

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Abstract

A 10 MW, 1.3 GHz multiple beam klystron (MBK) has been developed for the DESY X-FEL and International Linear Collider projects. The device uses six electron beams set off-axis on a large bolt circle which interact with a combination of higher-order-mode and conventional klystron cavities to efficiently produce high power RF. Extensive two and three dimensional simulations were used to design the device. Recent test results have validated the basic design concepts and procedure. Ten megawatts of peak and 150 kW of average power have been stably generated with 59% efficiency and 48 dB of gain.

INTRODUCTION

A higher-order-mode multiple beam klystron, designated the VKL-8301, has been developed for use as the amplifier in the RF accelerators of the DESY X-FEL and International Linear Collider. In this device, the electron beams are set on a large bolt circle diameter (far from the geometric axis of the device) and interact with the second radial peak of the axial electric field of the TM_{02} cavity mode.

There are both advantages and disadvantages of this device relative to both the conventional single beam klystron and the so-called fundamental-mode MBK in which the electron beams are clustered about the geometric axis of the device and interaction occurs in the fundamental TM_{01} mode, as in conventional klystrons. An advantage shared by both types of MBKs is their ability to produce high power with high efficiency at greatly reduced beam voltages compared to a conventional device. This results in a more compact klystron and a smaller, less expensive modulator. An added advantage of the higher-order-mode MBK is the ability to use cathodes of larger size (because they are not constrained by the physical size of the cavity as in a fundamental-mode MBK) which results in significantly lower cathode current density loadings. Lower loading corresponds to lower operating temperatures and an exponentially lowered rate of barium depletion from the cathode. This results in a significantly extended cathode lifetime and, because the rate of barium accumulation on high gradient surfaces in the electron gun is also reduced, an extended period of arc-free operation of the electron gun. Both are important considerations for managing operational costs in an accelerator using hundreds of klystrons. The relative disadvantage is an increase in the complexity of the klystron, particularly in the configuration required to focus and transport the off-axis electron beams.

Such a device has been designed and successfully tested. A brief overview of the design will be given and new test results will be presented.

DESIGN

The concepts defining the design and development of the MBK have been reported in [1]. Extensive two and three dimensional simulations were used to produce the klystron shown in Fig. 1 [2]. A novel magnetic focusing circuit in combination with a highly uniform solenoidal field is used to form and transport the six electron beams that have their local axes on a 26.7 cm diameter bolt circle. The confined-flow focusing with a moderate area convergence of 6:1 results in a well confined beam with a simulated scalloping of 9.5%. The RF circuit for each beam line consists of six cavities: large TM_{02} mode cavities in which all beams are present for the input and output and four separate conventional TM_{01} intermediate cavities for each beam. One of these conventional cavities is a second-harmonic cavity for efficiency enhancement. RF power is coupled out using two irises 180° apart in the output cavity. The power passes through two alumina

Figure 1: VKL-8301 multiple beam klystron.

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windows that have integrated half-height to full-height waveguide transformers. A bolt-on top coil is used to maintain the beam focusing through the output gaps until the beams dump into the six individual collectors. The klystron is 255 cm in length, has a major diameter of 53 cm and weighs 900 kg.

Several options were incorporated into the prototype's design to allow for diagnostics and fine tuning. Isolated collectors and separate feed-throughs for each cathode's heater circuit were important for determining beam current interception on the RF circuit and for characterizing the dynamic response of the higher-order-mode cavities. Fine tuning of the focusing field was accomplished using shunt resistors attached to the taps for the individual coils comprising the solenoid. The final configuration of the solenoid required just two power supplies operating at two different currents and consuming 5.0 kW of power. Finally, frequency tuners were included in the conventional klystron cavities that could be accessed through the solenoid. These were useful in reducing the initially high gain of the device.

OPERATION

Testing of the device has validated the basic design approach. Six 120 kV electron beams of measurably identical currents of 23.5 A each have been successfully propagated through the klystron circuit with 99.5% DC beam transmission and 97.5% transmission at fully saturated RF conditions and for full operating duty. Full 10 MW peak power and 150 kW average power have been achieved, although at a reduced efficiency of 59% than was originally desired. Table 1 shows a summary of the final test data.

Table 1: Summary of Test Data.

Parameter	Value
Frequency	1.3 GHz
Peak Power	10 MW
Average Power	150 kW
Efficiency	59%
Gain	48 dB
-1 dB Bandwidth	6.9 MHz
Beam Voltage	120 kV
Beam Current	141 A
RF Pulse Length	1.5 ms
Repetition Rate	10 Hz

The output power versus drive power characteristic curves are shown in Fig 2 for various beam voltages. The curves are free of discontinuities and are very similar to what would be observed in a conventional klystron. The bandpass curve at saturation is as shown in Fig. 3. The curve is slightly tilted at the high end due to tuning the second cavities in each beam line higher in frequency to compensate for an initially higher than desired gain. Regardless, the minimum -1 dB bandwidth of 3 MHz has been easily satisfied.

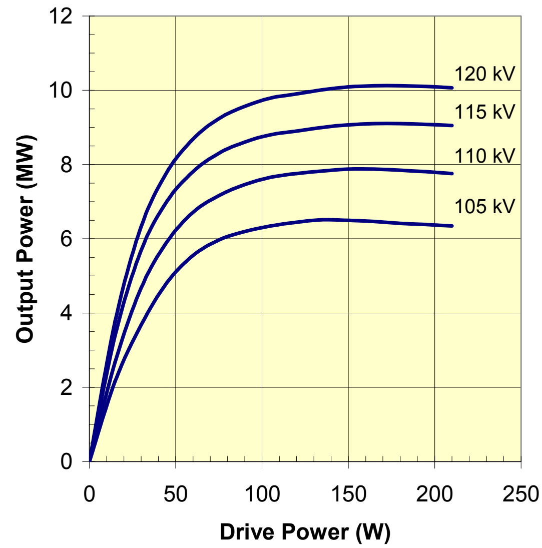

Figure 2: Output power versus drive power for several values of beam voltage.

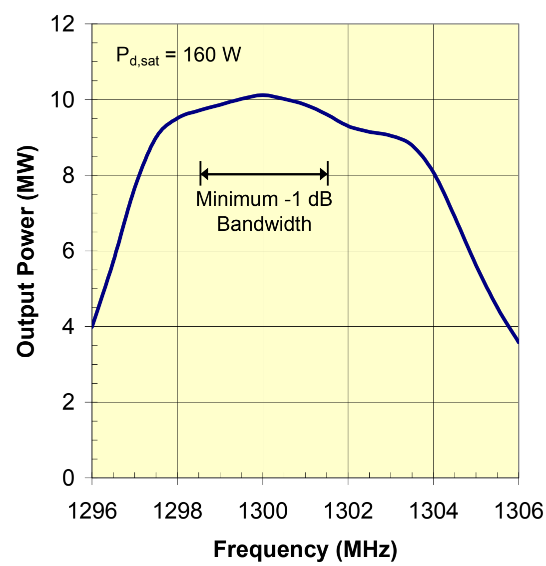

Figure 3: Saturated output power versus frequency.

The klystron also operates stably into a 1.2:1 VSWR mismatch at its output. This is a requirement from the accelerator specification which uses high power circulators that could present such a mismatch to the klystron. The test involves inserting calibrated mismatches into both waveguide outputs and varying the phase through 180 electrical degrees in six equal increments. Stability is judged by the lack of any discontinuities in the klystron's transfer curve at each phase of the mismatch. The test showed that the klystron had smoothly varying transfer curves and was stable. Approximately 11 MW of peak power at 1.3 GHz was stably generated into the high impedance phase of the mismatch which corresponds to an efficiency of 64.5%. This shows that the goal of a base efficiency of 65% into a

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matched load can be achieved through proper loading of the output circuit. However, the electrical design needs to be modified so that the klystron will continue to remain stable through the high impedance phases of the mismatch test at the higher base efficiency value.

CONCLUSION

The demonstrated focusing and propagation of high power off-axis electron beams and the subsequent generation of high peak and average RF powers with high efficiency has validated both the basic design approach and the simulation codes used for the design. Importantly, the achieved low cathode loading of 2.2 A/cm^2 results in a predicted cathode lifetime in excess of 100,000 operational hours. However, additional refinements to the RF circuit are required to meet the goal of 65% efficiency. These will be implemented in a future version of the klystron.

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