HIGH-POWER LOW-VOLTAGE MULTI-BEAM KLYSTRONS FOR ILC AND PROJECT-X*

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Abstract

Designs of two multi-beam klystrons with parameters suitable for ILC and for the 8-GeV pulsed stage of Project X (PX) have been developed. The chief distinction of these tubes from other MBKs is their low operating voltage, namely 60 kV for the ILC tube and 30 kV for the PX tube. Advantages of low voltage include no requirement for pulse transformers or oil-tanks for high-voltage components, and simpler modulators. A 6-beamlet quadrant of the ILC tube has been built and is soon to undergo tests; it is designed to produce 2.5 MW at 1.3 GHz in a 1.6 ms wide pulse at a 10 Hz pulse rate; a four-quadrant future version would produce 10 MW. The 6-beamlet PX tube is to produce 520kW, and would operate in one of two regimes, either at a repetition rate of 2 Hz delivering 30 ms pulses, or at 10 Hz delivering 8.5 ms-long pulses. The PX tube is currently undergoing engineering design, with construction scheduled for completion by the end of 2014.

INTRODUCTION

Multi-beam klystrons (MBKs) are the most advanced stage in the evolution of high-power klystron design. The distinct feature of MBKs is their relatively low-voltage beams (beam-lets) as compared to the single beam in traditional tubes. This provides numerous advantages: MBKs can use a simpler (and thus, a cheaper) modulator—or even a switched power supply; no pulse-transformer is required; and there is no need for a high-voltage oil tank to insulate the gun. An MBK can be made significantly shorter (e.g. by a factor at least 2) than a single-beam tube delivering the same power and pulse; in particular the collector length can be greatly reduced. The challenges associated with MBKs are typically to design the cavity chain where all parasitic modes are sufficiently detuned, which is accomplished by using a set of metal shunts inserted in some of the cavities to cause either inductive or capacitive detuning, particularly in the input and/or output cavities where the RF field interacts with all the beam-lets, or by using individual gain and penultimate cavities each serving a sub-group of beam-lets (beam-let cluster) and working at the fundamental mode. To easily match the beam between the gun, the cavities, and collector, the magnetic system is typically divided by iron pole-pieces into regions of independent control. An associated challenge is to have coil and pole-piece configurations where the transverse magnetic field on the axis of each beam-let is less than 0.5% of the longitudinal field, while keeping the magnetic system design relatively simple. In [1] and refs therein, detailed descriptions can be found of tools, methods, approaches and recipes to address the aforementioned challenges; in particular, contemporary state-of-the-art codes such as MAGIC [2], MERMAID [3], and DGUN [4] are invaluable in designing MBKs.

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MBK FOR ILC

In [1], the tube's conceptual design was presented. Herein we mention briefly its parameters and main features. Figure 1 presents the layout; the design parameters are shown in Table 1.

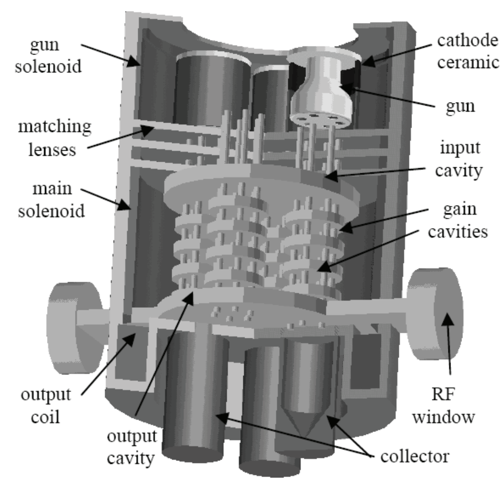

Figure 1: Layout of ILC MBK.

Table 1: Design Parameters of ILC–MBK

Operating frequency, MHz	1,300
Beam voltage, kV	60
Beam-let microperveance	0.85
Number of beam-lets	24
Beam-let current, Amps	12.5
Total current, Amps	300
Efficiency, %	65
Output RF power, MW	10
Average output power, kW	150
Pulse width, ms	1.6
Saturated gain, dB	50
Cathode loading, Amps/cm^2	2.7
Gun surface electric field, kV/cm	65
Total tube length, m	1

Note that the electron gun is divided into 4 sectors, each delivering 6 beam-lets. The input and output cavity are common for all beam-lets. The gain cavities are clustered, each serving a group of 6 beam-lets.

At present, to validate the design of the entire tube, and to minimize technical risk, Omega-P is building a single quadrant of the tube that has only 6 beam-lets. The 6-beamlet quadrant is to produce 2.5 MW at a 10 Hz repetition rate; the rest of its parameters are as shown in Table 1.

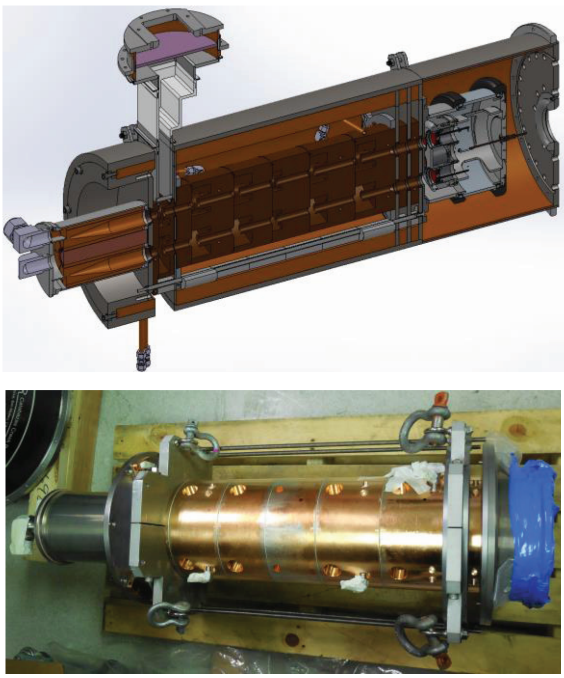

Figure 2: The 6-beamlet quadrant is to produce 2.5 MW at a 10 Hz repetition rate; the tube (at top) is shown inside the solenoid, and the cavity structure with the collector (at bottom) is photographed without the gun.

The 6-beamlet quadrant structure is being built for Omega-P by Calabasas Creek Research Inc. Presently the structure is undergoing final brazing. The magnetic system has been built by Stangenes Industries Inc. and is presently undergoing certification. The expectation is that the 6-beamlet quadrant will be ready for testing in the beginning of 2014.

MBK FOR PROJECT-X

The design parameters of this MBK are shown in Table 2. The tube is to operate at a gun voltage of only 30 kV.

Figure 3 shows a schematic of the tube. Its design incorporates many features found in the 6-beamlet quadrant of the ILC tube. The simulation work has been completed, and presently the engineering designs are nearly complete for the gun, collector, and the chain of gain, second-harmonic and penultimate cavities; the input and output cavities still require some simulation work to optimize the coupling (with a loop-like coupling element for the input cavity, and waveguide for the output cavity) while having the RF field distribution at the location of all 6-beam-lets as identical as possible. Fabrication of the magnetic system will begin soon.

Table 2: Design Parameters of PX–MBK

Operating frequency, MHz	1,300
Beam voltage, kV	30
Beam-let microperveance	0.85
Number of beam-lets	6
Beam-let current, Amps	4.4
Total current, Amps	26.4
Efficiency, %	65
Output RF power, kW	515
Average output power, kW	30/ 42.5
Pulse width, ms	30/ 8.5
Repetition rate, Hz	2 /10
Saturated gain, dB	46
Cathode loading, Amps/cm^2	2.1
Total tube length, m	0.85

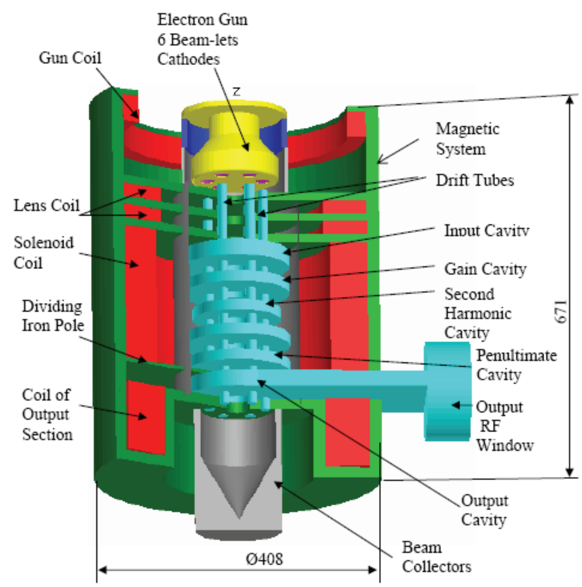

Figure 3: MBK for Project X.

As with the ILC MBK, the PX MBK has its magnetic system divided into several independent regions to allow good beam matching between the gun, cavities and the collector: an example is shown in Fig. 4. In addition, the solenoid around the cavity chain has a special periodic spacing which allows it to have very little transverse magnetic field (0.22 G max.) and only small ripples in longitudinal magnetic field (0.56 G peak-to-peak) at the locations of all 6 beam-lets.

The collector, shown in Fig. 5 is of a cellular design with cells uncoupled from one other; this feature helps to greatly reduce any space charge effects and parasitic mode oscillations.

The cavities operate in the fundamental TM_{010} mode; thus dealing with detuning of parasitic modes which would be required if operation were at higher-order modes is avoided.

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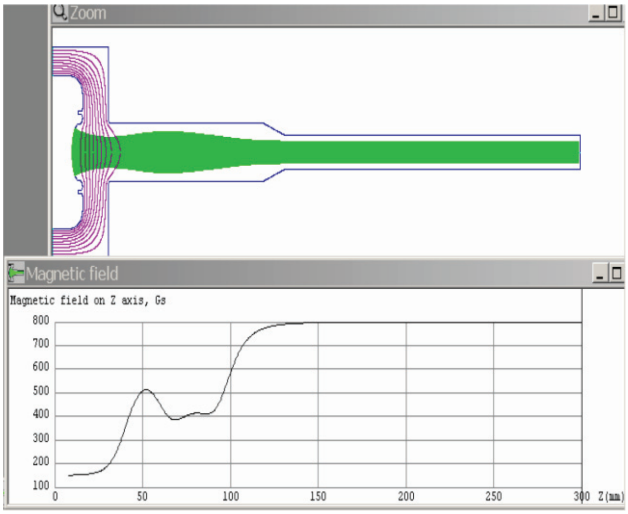


Figure 4: an example of electron beam matching in PX MBK. Horizontal divisions are 50 mm, and vertical divisions are 100 G.

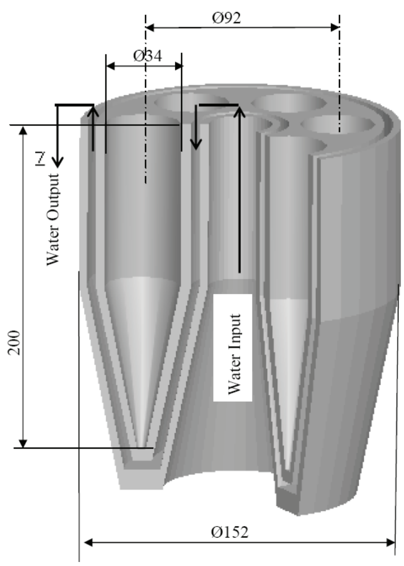


Figure 5: The collector with 6 cells for 6 beam-lets (see explanations in the text).

Figure 6 shows the typical distribution of electric field in a cavity. All cavities, except for the second harmonic cavity operate near 1300 MHz, while the second harmonic cavity operates near 2600 MHz; the latter is introduced to reduce the length of the interaction region and boost the tube efficiency.

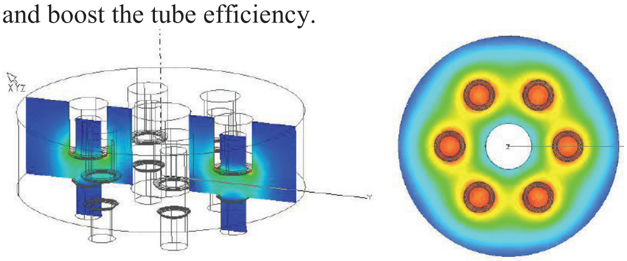
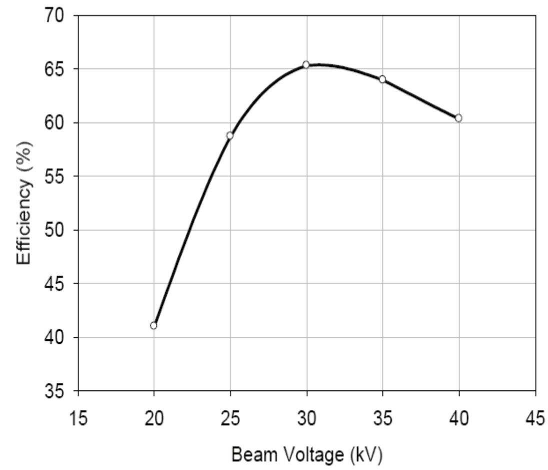
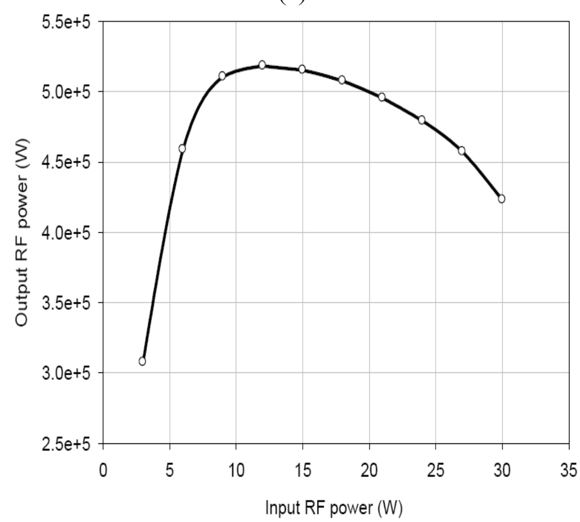


Figure 6: electric field in a cavity (see explanation in the text).

The computed efficiency and output power for the tube are shown in Fig. 7.



(a)



(b)

Figure 7: (a) efficiency vs. the beam voltage, and (b) the output power vs. the input one.

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