LOW BEAM VOLTAGE, 10 MW, L-BAND CLUSTER KLYSTRON*

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Abstract

Conceptual design of a multi-beam klystron (MBK) for possible ILC and Project X applications is presented. The chief distinction between this MBK design and existing 10-MW MBK's is the low operating voltage of 60 kV. There are at least four compelling reasons that justify development at this time of a low-voltage MBK, namely *i.* no pulse transformer; *ii.* no oil tank for high-voltage components and for the tube socket; *iii.* no high-voltage cables; and *iv.* modulator would be a compact 60-kV IGBT switching circuit. The proposed klystron consists of four clusters containing six beams each. The tube has common input and output cavities for all 24 beams, and individual gain cavities for each cluster. A closely related optional configuration, also for a 10 MW tube, would involve four totally independent cavity clusters with four independent input cavities and four 2.5 MW output ports, all within a common magnetic circuit. This option has appeal because the output waveguides would not require a controlled atmosphere, and because it would be easier to achieve phase and amplitude stability as required in individual SC accelerator cavities.

3D AND 2D APPROACHES

There are at least two ways of designing an MBK with given parameters. One way is by having a general idea of an arrangement of beam-lets, cathodes, cavities, and cavity modes and then to optimize geometry using three-dimensional codes (3D) for beam simulations [1]. The second way is to reduce the problem to two-dimensions (2D) by minimizing 3D effects and using widely available 2D codes for beam dynamics simulations.

For designing an L-Band MBK, the second way is quite realizable. In this approach, each beam-let is considered as a 2D entity in the gun, interaction region, solenoid, cavities, and beam collector. That approach accelerates considerably the design process for the device. An estimation of the influence of 3D effects is needed, of course, but this can be made after a 2D design is at hand.

LOW BEAM VOLTAGE MBK

The term "low voltage" is applied for comparison with existing 10 MW L-Band klystrons which use 120 kV power supplies [2-3]. The present aim is to develop a klystron with a beam voltage of half that value, i.e. 60 kV, and with 24 individual beam-lets.

Low voltage is favourable for several reasons. The first advantage is its requirement for a simpler and cheaper modulator, and lack of need for a high-voltage gun tank. The second advantage is a reduction of thermal loading on the beam's drift channel by as much as a factor-of-4. With further increase in the number of beam-lets one can even consider a CW L-Band klystron generating 5-10 MW of power. A further advantage that accrues is a reduction by about a factor-of-2 in the tube length, as compared with the Toshiba, CPI and Thales L-band tubes [2-3].

CLUSTER CONCEPT AND OPERATING MODE IN THE CAVITY

The basic new MBK concept is that a group of beam-lets, in this case six, make a compact ring formation. They can be considered as cluster, formed by one cluster gun as

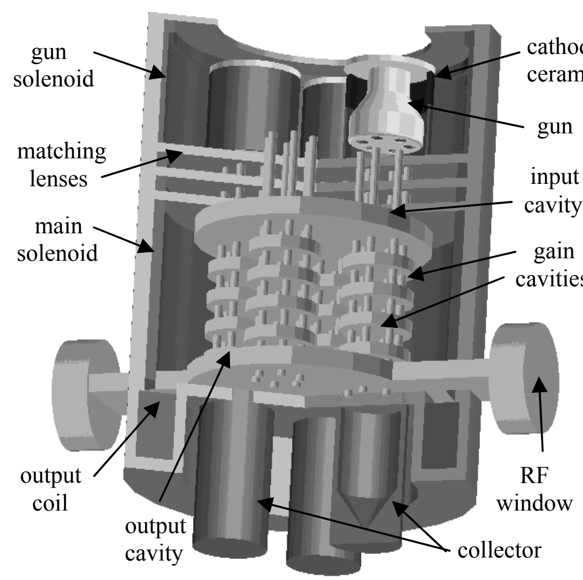

Figure 1: Layout of cluster MBK.

shown in Fig. 1. On the one hand, the clusters should be far enough from one another so that the cluster guns are independent. On the other hand, the distance between guns should be minimized so as to not to increase more than necessary the cross-sectional area of the cavities.

Such a configuration is realized by the choice of a particular cavity operating mode, shown in Fig. 2. The mode can be named as a "chain TM_{210}" mode in a ring shaped cavity, herein designated "chain mode cavity" (ChMC). The full number of bean-lets is equal to 6×4. Similarly, one can consider a six-link ChMC with number of beam-lets 6×6, using the chain TM_{310} mode. As Fig. 2 shows, the mode consists of four ring formations, each of which is similar to a TM_{010} mode in a toroidal cavity. At

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nulls of the RF magnetic field and at maxima of the RF electric field, beam-let drift tubes are located.

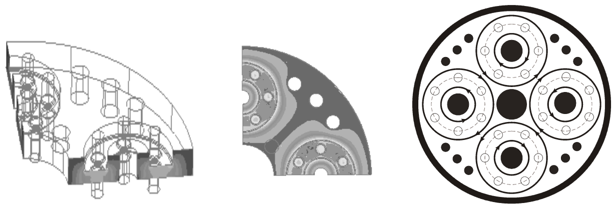

Figure 2: Operating mode chain TM_{210}. Shown are the electric field pattern, layout view of magnetic field, shunts which form the field shape, and position of drift tubes for beam-lets.

NEIGHBOURING MODES

Resonance frequencies of neighbouring modes should be as far away from the frequency of the operating mode as possible. An increase in the gap between frequencies of the nearest higher and lower modes would mean an increase in electric coupling between regions of the cavity that is not possible in existing geometry. Tuning of the next modes is carried out by the inductive and capacitor elements placed in the cavity region (see Fig. 2). In our case this succeeded in shifting frequencies of the nearest upper and lower modes by about 100 MHz.

Modes of the cavity with frequencies close to high RF harmonics on the beam current may be dangerous as well. These require detuning also.

The output circuit of the output cavity should load these modes so as to reduce of their amplitude. The harmonic composition of the output signal and the influence of RF harmonics on the output waveguide and on the load need to be topics of experimental study.

GAIN CAVITIES

Input and output cavities are common for all 24 beam-lets. The distance between clusters allows room in the interaction region for intermediate (i.e., gain, penultimate) ring-shaped cavities that interact with clusters composed of 6 beam-lets, as shown in Fig. 3. In intermediate cavities, the TM_{010} mode is used. For reduction of length of the interaction region and increase of efficiency, in every cluster one cavity is tuned on the frequency of the second harmonic of current of a beam (SHC).

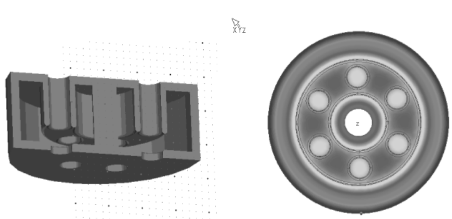

Figure 3: Intermediate Cavity. Fundamental mode TM_{010}.

Use of cavity with a fundamental mode removes all problems which take place in cavity with higher order modes. However nothing prevents one from installing all cavities of one type - ChMC, and relinquishing SHC. The point is only concern for design and technological feasibility of the project and in cost of the device.

MAGNETIC SYSTEM

The magnetic system is divided by iron pole pieces into regions of independent control. These are regions of the gun, the matching optical system consisting of pair of lenses, the solenoid, and the output coil, shown in Fig. 4.

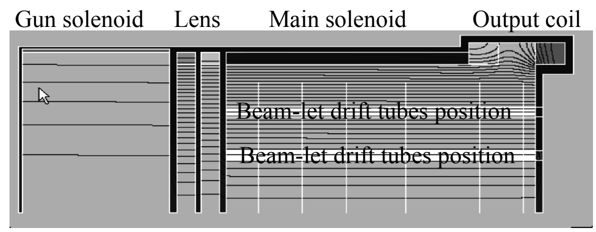

Figure 4: Shape of magnetic system, MERMAID simulation [5].

The system of coils provides compensation of transverse fields on the axis of each beam-let to a level of $\pm 0.5\%$ of the longitudinal field. Non-compensated values are the angular components of magnetic field produced by beam currents. The cross-sectional area occupied by a total beam current is big enough, and the transverse fields produced by this current do not exceed the above-mentioned level.

MATCHING MAGNETIC OPTICAL SYSTEM

For the first time the concept of a matching double-lens magnetic system was formulated for the Toshiba L-Band MBK [2]. It was a rather convenient tool for adjustment of the tube. Independently changing magnetic fields in the regions of the gun, lenses, in the solenoid it is

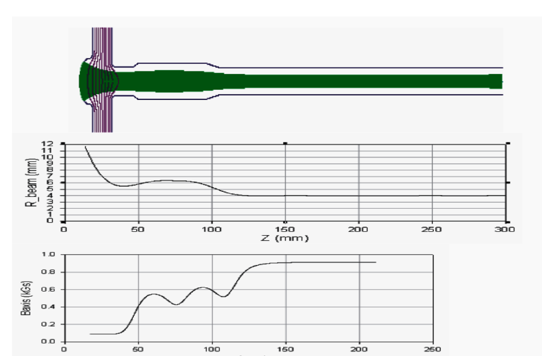

Figure 5: Matched beam profile, showing trajectories, beam radius and beam-let axis magnetic field shape. Magnetic field is twice the Brillouin field. DGUN simulation [6].

possible to match a beam without scalloping over a wide range of beam diameters and to change magnetic field from 1 to 2 times or more of Brillouin field (see Fig. 5).

THE CATHODE AND BEAM OPTICS

Choice of low cathode loading equal to 2.7 A/cm^2 is positive both from the point of view of lifetime of the cathode and for reduction of intensity of electric field on the surface of a focusing electrode down to 65 kV/cm which is considered safe for electron devices with a voltage pulse width equal to a millisecond and more. The choice of cathode geometry can minimize this value too. An estimation of 3D effects arising from nearest beam-lets and their cathodes shows that they do not exceed 5 %. This implies that the perveance in 3D geometry can differ from model-based 2D geometry by about 5%, and difference of axes of the ellipse formed by a contour of a beam-let does not exceed of 5%. This criterion seems quite acceptable. The beam is rather sensitive to cathode conditions, but the application of the confined flow and increasing of magnetic field up to value of twice the Brillouin field stabilizes its geometry sufficiently, as can be seen in Fig. 5.

CLUSTER GUN

For practicality, the gun is divided into four structurally independent cluster guns with 6 beam-let cathodes in each. This is dictated by the huge required total micro- perveance, equal to 20.4. A gun with such a perveance be susceptible to parasitic oscillations. A cluster gun with a total micro-perveance of 5, can probably avoid this danger.

Electric coupling of neighbouring cluster guns is possible. It will be experimentally necessary to investigate and apply absorbing material into the gun tank in order to suppress parasitic oscillation if needed.

Table 1: Design Parameters of Low Beam Voltage, 10 MW, L-band Cluster Klystron, using High Order Chain Mode Cavities

operating frequency	1300	MHz
beam voltage	60	kV
number of beam-lets	24	
beam-let current	12.5	A
beam-let micro-perveance	0.85	
total beam current	300	A
simulation efficiency	65	%
output RF power	10	MW
average output RF power	150	kW
RF pulse width	1.5	ms
saturated gain	50	dB
cathode loading	2.7	A/ cm2
gun surface electric field	65	kV/cm
total tube length	100	cm

COLLECTOR

The volume of a collector can support parasitic oscillations, as well as to reflect by a space charge electric field of the beam a part of delayed electrons. Therefore the collector for this tube is divided into four electrically independent parts in order to reduce space charge effects. Simultaneously, while maintaining acceptable thermal loading on the collectors, this enables a reduction in their length. Further reduction in collector size would results from use of 24 independent micro-collectors, one for each beam-let.

Table 1 summarizes parameters of the cluster MBK discussed in this paper,

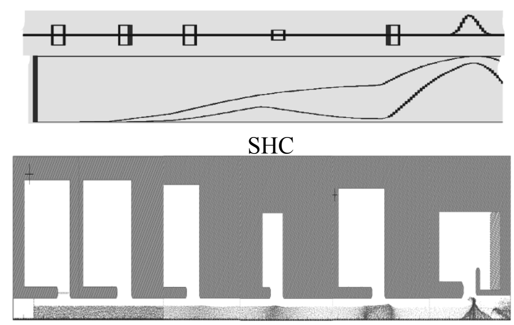

Figure 6: 2D approach for simulation of beam-let dynamics. 3D cavities are changed with equivalent 2D. Harmonics of beam current are shown. MAGIC simulation [4].

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