DESIGN AND SIMULATION OF MULTIBEAM KLYSTRON CAVITY

Ashish Kumar Tiwari[#], Rajiv Kumar Arora, P. R. Hannurkar

Raja Ramanna Centre for Advanced Technology, Indore, India.

Abstract

The design and simulation of a multibeam re-entrant type cavity with four beams is presented for a 350 MHz, 250 kW CW klystron. The simulation is carried out using electromagnetic code CST Microwave Studio. This klystron will be used for 100 MeV proton Linac for Spallation Neutron source (SNS). Important Simulation results are presented.

INTRODUCTION

Klystrons have the inherent capability to provide maximum gain per unit length among the conventional electron beam devices. With the practical limits on increasing the number of cavities for a higher gain, increasing the output power level in conventional klystrons means increasing either operating voltage or the beam current. For increase in current the perveance of the gun is to be increased which results in increased space charge forces and the reduced efficiency of the device. Further high magnetic field is required to keep the beam focused throughout the drift length. Increase in anode voltage is limited by thermal and voltage breakdown considerations. A number of klystrons may be paralleled to get more power output and increased redundancy but phase matching at output remains a troublesome part of any such arrangement. Further any such arrangement is bulky and requires room.
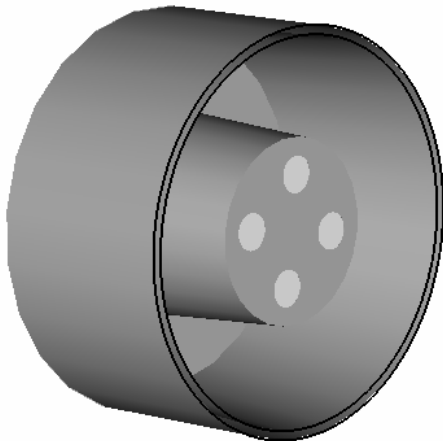

Figure 1: Cross-section of a multibeam cavity with four beamlets.

Another option is to parallel a number of beams within the same interaction structure. Since all the beams are accelerated through a common voltage and interaction takes place in a common structure namely multibeam

[#]atiwari@cat.ernet.in

cavity so the problem of phase matching no longer exists. This type of device is called the Multi-Beam Klystron (MBK). After the first experimentation in 1940's these klystrons have been developed and manufactured especially in Russia for past few decades. The multibeam klystrons are being looked into with renewed interest worldwide for their large scale application in accelerators. RRCAT has taken up the development of 350 MHz 250 kW CW klystrons for the accelerator applications. This paper presents the design and simulation of a multibeam cavity to be used as an interaction structure for the multibeam klystron.

DESIGN OF RE-ENTRANT CAVITY WITH MULTI-BEAM CHANNEL

Analytical methods can be used for the estimation of parameters of the cavity having simple shapes but for the more complex shapes experimentation or computer simulation are the only resorts. Analytical methods are still required for initial estimation of input geometrical parameters in computer models to be further analyzed and optimized numerically. The parameters were determined from the coaxial line analogy and parallel resonant circuit. Figure 1 shows the cavity shape. The RF interaction circuit for MBK is re-entrant cavity operating in TM_{010} mode. The diameter of gap channel is much larger than that of single beam klystron cavity in order to hold more beam channels. Therefore the RF electric field in inner layer beam channels is stronger as compared to outer layer beam channels. It is found that the electric field is not constant and slightly asymmetrical over the cross section of four beams for slightest disparity in interaction gap and field is more at the central beam if it exists. Therefore the radial dimension of the cavities must be chosen in order to minimize the disparities between the interaction gaps.

Suitable choice of the diameter of the gap projection is important for MBK design as it will influence the beam wave interaction and hence the efficiency. The following relation between cavity diameter and the diameter of gap projection is to be satisfied according to calculation and experience [1]

$$\frac{D_p}{D} < \frac{3}{4} \tag{1}$$

$$\frac{D}{\lambda} < \frac{3}{4} \tag{2}$$

where D_p = Diameter of gap projection
D = Diameter of cavity
λ = Operating wavelength

Beam and tunnel diameter are decided so that it can be easily focused and radial beam coupling coefficient having less than 3% variation. Figure 2 shows the equivalent circuit of the cavity for the purpose of determining the parameters from the coaxial line analogy and parallel resonant circuit [2].
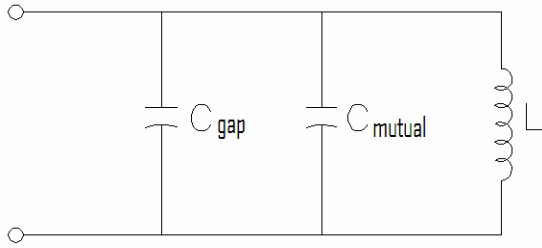

Figure 2: Equivalent Circuit of a multibeam cavity.

The inter gap capacitances C_{gap} plays the vital role in deciding the   frequency of operation. In the drift tube inside the cavity the total area of cross section of annular portion is made to be equal to the area of its single beam counterpart. Gap capacitances are determined from it with gap distance estimation from beam coupling coefficient. The inductance value is considered as an inductance of a coaxial line where the diameter of the inner conductor as the diameter of the circle where the beams are placed. Beam position is kept such that the mutual interaction between them may be less pronounced. At a first approximation the mutual capacitances were neglected as these may be taken care by optimisation through computer simulation [3].

PHYSICAL MODEL AND COMPUTER SIMULATION

Being an asymmetric structure such a cavity need to be modeled in a 3D code. CST's microwave studio is used for the purpose. One such cavity, whose initial geometric parameters are calculated analytically as above, is modeled and analyzed using the CST Microwave Studio. Cavity is crossed by all the beams in parallel according to the figure 1. The resonant mode is the fundamental mode (TM_{010}).

CST Microwave Studio employs the combination of the proprietary perfect boundary approximation (PBA) with the Finite Integration Technique (FIT). It has a simple 3D figure input interface. According to the estimated geometrical parameters cavity was modeled using the template based GUI modeler in Microwave Studio [5]. The frequency for different modes with the associated Q value is listed below.

Table 1: Separation of modes

Mode Number	Frequency (MHz)	Q Value
1	350.00	9655
2	763.91	11908
3	991.97	16488

RESULTS AND DISCUSSION

Eigen-mode AKS solver is used with interpolated quasi Newton optimization routine. Table 1 indicates that the modes are sufficiently separated.   From the field distribution inside the 4-gap cavity for different modes, mode 1 is clearly identified as dominant TM_{010} mode. R/Q for the geometry shown is found to be 68 with Q factor of about 9,655. R/Q is optimized by varying gap and subsequent cavity height for the resonant frequency. The R/Q factor of a conventional cavity is given by

$$\frac{R}{Q} = \frac{V^2}{2\omega U} \tag{3}$$

where V is the RF voltage across the gap and U the electrical energy stored in the gap. If C is the capacitance of the equivalent circuit, $U = CV^2/2$ and then $R/Q = 1/\omega C$. Now MBK cavity is made of 4 such capacitance so R/Q factor related to a single beam counterpart is $R/Q = 4/\omega C$. Therefore the instantaneous bandwidth is significantly large in this case. Effects of fabrication errors and geometrical changes are being investigated.
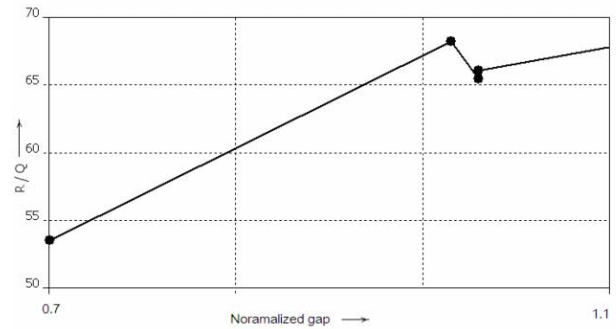

Figure 3: Variation of R/Q with normalized gap distance for dominant mode.

REFERENCES

[1] Ding Yaogen et al., Theortical and Experimental Research on Multi-beam Klystron, Proceedings of High Energy Density Microwaves Conference, Pajaro Dunes, California, 1998

[2] K. Fujisawa, General treatment of klystron reentrant cavities, IRE Trans. Microwave theory Tech., vol. 6, pp. 344-358, Oct. 1958

[3] A. Ghose et al, RF Cavity Design for A Multibeam Klystron, Proc. of National Symposium of Indian Vacuum Society, 1998

[4] E. A. Gelvich, The New Generation of High Power MBK, IEEE, MTT, Vol 41, No.1 Jan 1994

[5] CST Microwave Studio User's Manual.