Design of RF Interaction Structure for a 352.2 MHz, 100 kW (CW) Power Klystron

Deepender Kant [1], L M Joshi [1], and V Janyani [2]

[1]*MWT Area, CSIR-CEERI, Pilani, Rajasthan-India*
[2]*Department of ECE, MNIT, Jaipur, Rajasthan-India*
dkc@ceeri.ernet.in
lmj1953@gmail.com
vijayjanyani@gmail.com

Abstract: **A 352.2 MHz klystron with an output power of 100 kw (CW) is under development at CSIR-CEERI for charged particle accelerator application. A study for the design of RF interaction structure of this klystron has been carried out to get the optimized design parameters. Initially 1-D code AJDISK has been used to predict the interaction parameters of RF structure which is optimized using MAGIC(2D/3D), to get the desired performance of the device. CST Microwave Studio has been used for design of input and output coupler. The paper shall present various simulation results of beam wave interaction.**

I. INTRODUCTION

A 352.2 MHz, 100 kW (CW) power klystron is under development at CSIR-CEERI, Pilani for application as high power RF source in accelerator based system. The target specifications of the device are given in Table-I. The klystron is under development after getting the optimized design parameters.

The electron gun and collector for this klystron have been successfully designed and developed earlier. The device has been characterized as diode and its performance has been found in close agreement with the design [1]. A typical snapshot of measured current and voltage using a pulsed power supply is shown in Fig. 1. The present paper deals with the simulation study for the RF interaction region of the tube.

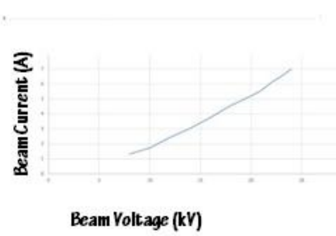

Fig.1 Measured V-I characteristic of the Electron gun

II. DESIGN OF RF INTERACTION STRUCTURE

RF section is an important part of a klystron which consists of RF cavities along with drift tube sections. Electrons emitted from the electron gun interact in RF structure with electromagnetic field to amplify it by transfer of their kinetic energy. The energy left in the beam is allowed to dissipate on the collector in the form of heat.

Table I

Device Specifications

Parameters	**Specifications**
Frequency (MHz)	352.2
Output Power (kW)	100.0
Gain (dB)	45
Efficiency (%)	45-50
Beam voltage (kV)	30
Beam current (A)	7
Magnetic field (Gauss)	200

For the design of RF section, empirical formulas [2] have been used to get initial design parameter which are used as input to large signal 1-D code AJDISK for getting a first stage estimation of the design parameters. RF cavity dimensions as well as cold test parameter like frequency, Q and R/Q have been optimized using SUPERFISH as well as MAGIC codes.

Design of the input cavity:

Input cavity is used to impart velocity modulation in the electron beam. A simulation result of the input cavity using SUPERFISH code is shown in Fig.2, giving the desired resonant frequency.

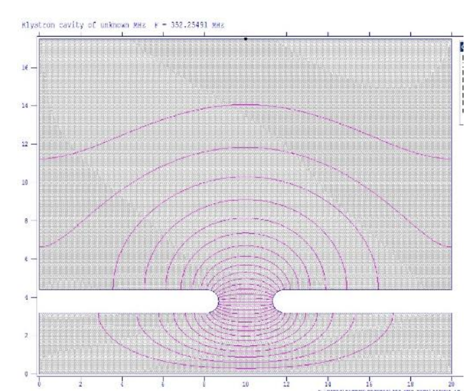

Fig.2 Simulation of input cavity in SUPERFISH

Beam wave interaction simulation:

The interaction between the electron beam and the RF signal in the RF section of the klystron resulting in amplification of latter has been simulated first using 1-D code AJDISK. Here the electron beam is considered to be made up of a number of disks of charges, which are of same diameter as that of un-bunched beam. It is assumed that focusing is strong enough so that beam diameter does not change due to space charge forces in un-bunched beam. The model calculates the bunching of the beam in the drift space as a result of the interaction of beam with RF at the gaps of the cavities and the energy extraction at the output gap. The cavity parameters such as frequency, Qs, R/Q and gap lengths and separation between successive cavities are given as input and output is generated by the code as shown in Fig. 3. By iterative simulation process we have found the desired output power i.e. 101.3 kW along with desired gain parameter, as shown in the output result.

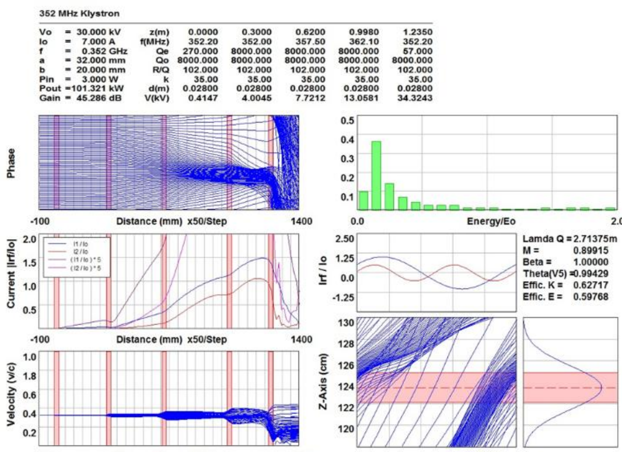

Fig.3 Simulation through AJDISK code

After getting initial design parameters of the RF interaction structure through AJDISK, all the RF cavities are characterized individually for their frequency, Q and R/Q etc. through simulated colt testing using MAGIC code. For example the

Input cavity resonant frequency is 352.2 MHz and the required external Q factor is 270. The results obtained through simulation are shown in Fig.4 and Fig.5 respectively (simulated Q value is 266).

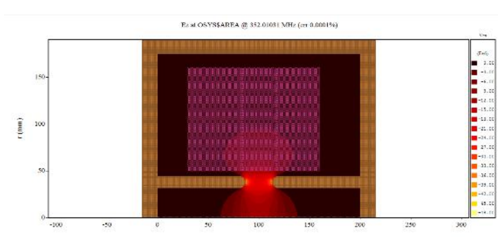

Fig.4 Simulation of resonant frequency of the input cavity through MAGIC

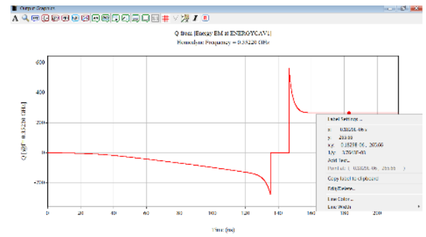

Fig.5 Simulation of the External Q parameter

Input Coupler Design

Practically RF power is fed in the input cavity through loop coupling. In the MAGIC simulation we have adopted external field on the gap line which is a new boundary (a straight line between the nose cone of the cavity). The external field $E_z(z, t)$ is calculated primarily as the electric field of the trapped mode at the operating frequency

$$E_z(z,t) = \frac{V_g}{d} f(z) \sin \omega t \quad (1)$$

Where V_g is the gap voltage, d is the gap length and f (z) is the field profile along the gap.

However the practical input coupler via loop along with a cavity tuner has been simulated in CST Microwave Studio as shown in Fig. 6 and the resulting S_{11} parameter plot of Fig.7 shows the required resonant frequency and also gives the Q parameter value of 272.4 after calculation against the required value of 270.

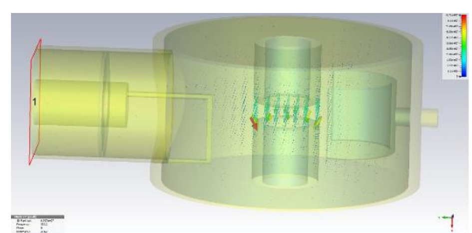

Fig.6 Simulation of the input cavity with coupler

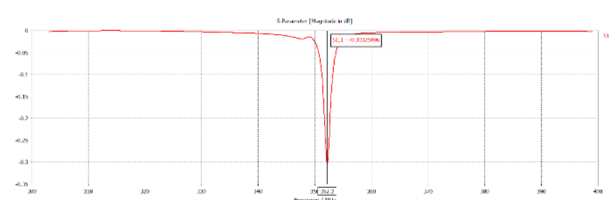

Fig.7 Plot of S11 parameter vs Frequency

Design of Intermediate cavities:

The present design employs two intermediate cavities to increase the gain (as well as band width by stagger tuning) and the penultimate cavity to increase the efficiency. The resonant frequencies for each cavity and their mutual spacing is simulated as per AJDISK results. The second cavity dimensions have been kept the same as the first cavity with same tuning arrangement. The MAGIC simulation results for the third and fourth cavity are shown in Fig. 8, Fig. 9 and Fig. 10 depicting resonant frequencies and shunt impedance.

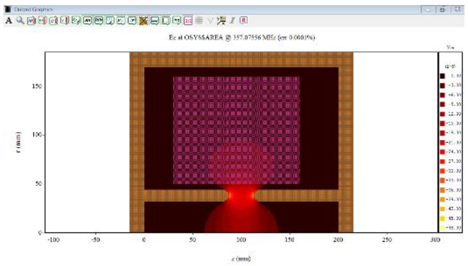

Fig.8 Simulation of third cavity at 357 MHz

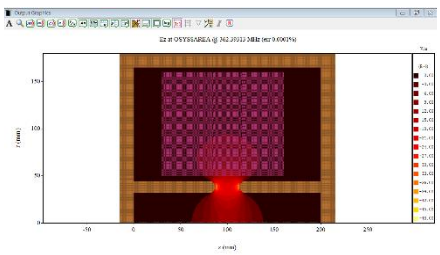

Fig.9 Simulation of fourth cavity at 362 MHz

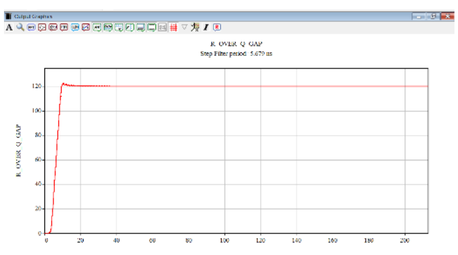

Fig.10 Simulation of 'R over Q' at cavity gap

Output Cavity Design:

The primary purpose of the output cavity is to maximize the RF power extraction and also to avoid particle reflections. Also a suitable coupler is required to efficiently couple the RF power to external load. The design of the output cavity along with a door-knob type coupler [3] is simulated in CST Microwave Studio as shown in Fig.11. The resulting S-parameter plot gives $Q_L = 39.2$

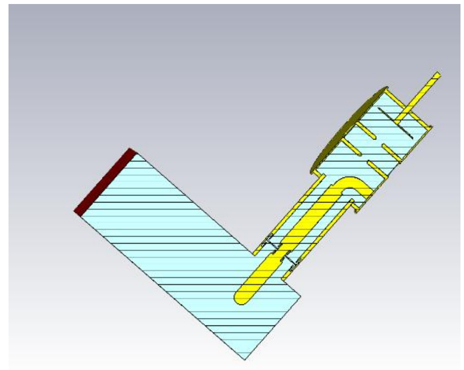

Fig. 11 Simulation of the output cavity

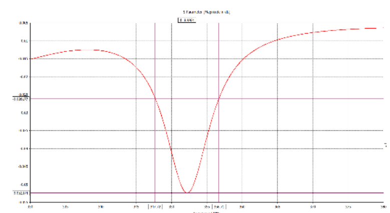

Fig.12 S-parameter plot of output cavity

After characterization of all cavities, the complete RF interaction structure has been simulated in MAGIC code as shown in Fig.13, which after many iterations through variations in spacing of the cavities and tuning of the frequencies, gives the desired output power (about 105 kW) as shown in Fig.14.

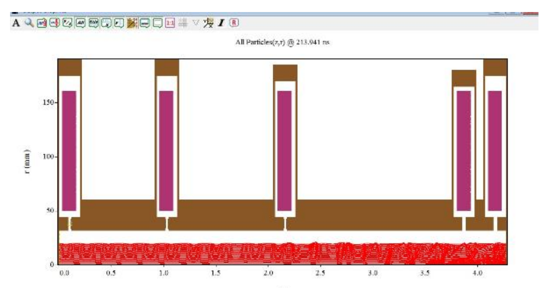

Fig.13 Phase space plot after MAGIC simulation

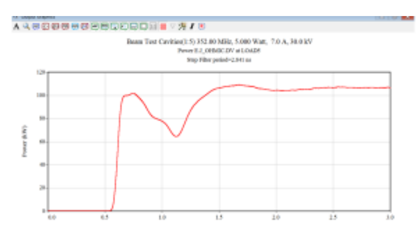

Fig.14 Simulated output Power in MAGIC

Table II

Parameters	**Specifications**	**Achieved through simulation**
Frequency (MHz)	352.2	352.2
Output Power (kW)	100.0	101.3
Gain (dB)	45	45.28
Efficiency (%)	45-50	48.23
Beam voltage (kV)	30	30
Beam current (A)	7	7
Magnetic field (Gauss)	200	200

CONCLUSION

A design of the RF interaction structure for a 352.2 MHz, 100 kW (CW) power klystron has been done using AJDISK and further optimized using PIC code MAGIC. The results achieved through simulation are close to the target specifications as shown in Table II. The results will be validated after performance evaluation of the klystron under development based on the optimized design parameters reported in the paper.

REFERENCES

[1] Deepender Kant, Bijendra Kumar, V S Rawat, Rakesh Meena, Pankaj Sharma,Debasish Pal, A K Bandyopadhyay and L M Joshi, “Design and Development of a Beam Stick Tube for 352.2 MHz, 100 kW (CW) Power Klystron,” *VEDA 2014* at DAVV, Indore, India

[2] Barker, Booske, Luhmann Jr. & Nusinovich, “Modern Microwave and Millimeter-wave Power Electronics,” *John Wiley & Sons, Inc.*

[3] Sandeep Vyas, Narendra Shekhawat, Shivendra Maurya, and V.V.P. Singh,“Computer Simulation and Analysis of 350-MHz High-Power Coaxial RF Window and T-bar Transition,” *IEEE Transactions on Plasma Science*, vol. 40, no.10, October 2012

[4] Paul J.Tallerico, “Design considerations for High Power Multicavity Klystron”, *IEEE Transaction on Electron Devices, Vol. ED-18 No.6, June 1971.*