DESIGN CONSIDERATION TO PPM KLYSTRONS FOR INDUSTRIAL LINAC

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Abstract

Toshiba has been developing the C-band and X-band Periodic Permanent Magnet (PPM) focused klystron in collaboration with KEK and manufactured prototypes for the JLC project. [1] The PPM klystron has an advantage to enhance the total efficiency as a result of eliminating the electric power for the focusing magnet. From experience on the development the PPM focused klystrons for the JLC project, we plan to apply the PPM focused klystron to the medical and industrial linac. The periodic magnet focusing scheme has some technical difficulties such as stop band voltage. To design the PPM klystron for the medical and industrial linac, it is necessary to give heed to electron beam instability; so that the tube parameters of the PPM focused klystrons have some constraints. The size of the accelerator system is substantially reduced if a PPM focused klystron is used. The majority of medical and industrial linacs use frequencies of S-band range. We discuss the availability of the S-band PPM focused klystron in this paper.

1 INTRODUCTION

Electron linacs have been widely used medical in applications. Recently sterilization of medical products and foods identified as possible applications for an Electron linac. Most of these linacs use S-band microwave (about 3 GHz). If a PPM focused klystron is used for these linacs, the size of the accelerator system is substantially reduced. Our design considerations to PPM Klystron for these linacs are reported.

2 PPM KLYSTRONS

PPM focusing system is utilized commercially in Traveling Wave Tubes (TWT) devices. In PPM focusing system, the axial field polarity is changed with every magnet. The configuration of the magnet is shown in Figure 1. To generate alternative polarity magnetic field on axis, ring permanent magnets that are axially magnetized with alternative polarity are placed between pole pieces.

So far, PPM focusing system is rarely employed in the klystrons. Because klystron cavities are radially extruded from drift diameter, the PPM configuration is complicated. The distance between the magnet rings to be placed on cavities is larger than the cavity height, so the PPM pitch is in disorder at the cavities, or the pitch is not small enough. The beam density in the klystron is gradually increased along drift tube by bunching. The density at the output cavity is much different from the density at input cavity. It was difficult to design a PPM focused klystron caused by the disordered magnetic field and the varying of the beam density.

Now, sophisticated simulation codes for magnetic field and for klystron beam simulations with PPM magnetic fields become available. And the rare earth metal magnet with high-energy product like Nd-Fe-B can be procured in reasonable price those enables us to design PPM focused klystron.

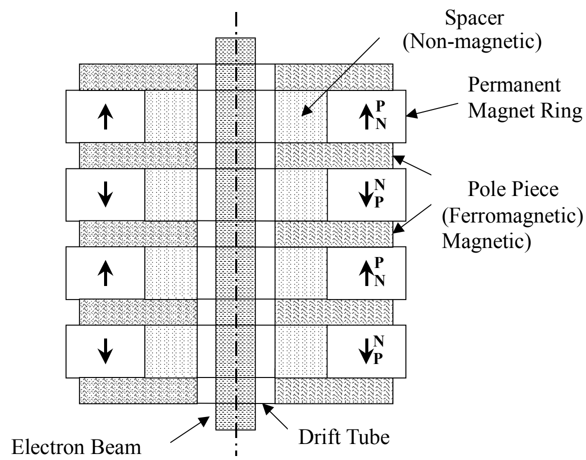

Figure 1 PPM Focusing system

The PPM focusing system was firstly applied to a high power pulsed klystron by SLAC for the NLC project. [2] At SLAC, X-band 50MW PPM focused klystron (XL-PPM) was successfully developed in 1997. In 1999, Toshiba was awarded the contract with SLAC on industrial manufacturing of XL-PPM klystron. Other PPM focused klystron development acuities are under way in TOSHIBA in collaboration with KEK; 50MW C-band and 75MW X-band pulse klystrons. The performance of these PPM focused klystrons were reported by H. Matsumoto and Y. H. Chin et al. [3][4]

The configuration of PPM focused klystron unit is shown in Figure 2. The cavities should be located between pole pieces. The cavity length is one of the constraints to design the magnetic circuit. Body section (cavities and drift region) is slim. However, even PPM focusing system, a small solenoid coil (Gun coil) is necessary around electron gun to control the beam. Power

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consumption for the gun coil can be several hundreds watts, and the cooling is done by air.

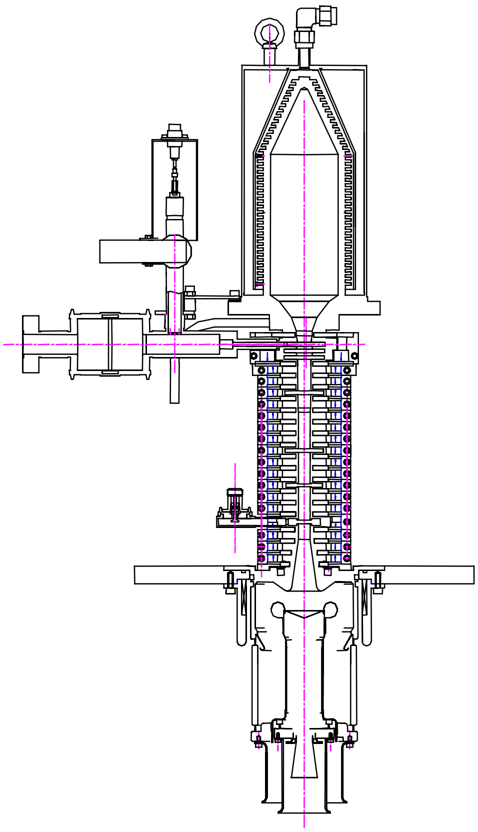

Figure 2: Configuration of PPM focused klystron unit

3 KLYSTRON DESIGN

The design parameters for the Toshiba PPM klystrons are shown in Table 1.

The root mean square value of the magnetic field required for PPM focusing system is larger than the Brillouin magnetic field strength. The ratio of the Brillouin field strength to PPM focusing field strength (peak) for our klystrons is expressed as below:

$$Bz / Bb \approx 2$$

In the design of PPM focusing filed, most important parameter is the stop band voltage, Vs, that voltage below which no beam transmitted. The stop band voltage must be much lower than the operating voltage. PPM focusing field works as a high-pass velocity filter. The stop band voltage is dependent on the peak PPM focusing field strength and the PPM pitch. The ratio for our klystron is expressed as below:

$$Vb / Vs \geq 14$$

Table 1:Design parameters of tour PPM klystrons

Parameter	E3758	E3768
Frequency	5712 MHz	11424 MHz
Output Power	50 MW	75 MW
Beam Voltage	350 kV	480 kV
Beam Current	316.8 A	282.7 A
Beam Perveance	1.53 μ perv.	0.85 μ perv.
Brillouin field	1129 Gauss	1554 Gauss
Bz (peak)	2000~2600 Gauss	3200~3700 Gauss
Reduced Plasma wavelength	0.764 m	0.662 m
Lamor wavelength	0.11~0.14 m	0.10~0.11 m
PPM Pitch	30 mm	25 mm
Stop band voltage	15~25 kV	26~35 kV
Vb/Vs	14~23	14~18

3.1 PPM FOCUSING FIELD

We considered availability of the S-band PPM focused klystron based on the scaling from above actual values of C- and X-band PPM klystrons.

The design parameters for our S-band klystrons are shown in Table 2.

Table 2:Design parameters of our S-band klystrons

Parameter	E3772	E3730A
Frequency	2856 MHz	2856 MHz
Output Power	7.5 MW	50 MW
Beam Voltage	160 kV	320 kV
Beam Current	115 A	380 A
Beam Perveance	1.8 μ perv.	2.1 μ perv.
Brillouin field	391 Gauss	578 Gauss
Bz (peak)	782 Gauss	1156 Gauss
Reduced Plasma wavelength	0.93 m	1.37 m
Lamor wavelength	0.23 m	0.24m
PPM Pitch	50 mm	55 mm
Stop band voltage	6.4 kV	16.7 kV
Vb/Vs	25	19.2

PPM focusing field strength (peak) of 800~1200 Gauss is needed for S-band klystrons. The SUPERFISH code is used for the cavity design. The cavities must be accommodated under the ring magnet and between pole pieces. The magnet ring placed on cavities must have larger inner diameter than outer diameter of cavities. From the SUPERFISH calculations, outer diameters of cavities are approximately 90 mm. The PPM pitch is determined from height of cavities. The ring magnets for the S-band PPM focused tube have an inner diameter of 120mm and an outer diameter of 144mm. Figure 3 shows the magnitude of axial PPM focusing field. Stop band voltages are much lower than the operating voltage. It is possible that the PPM focused klystron can replace as the solenoid focused tube.

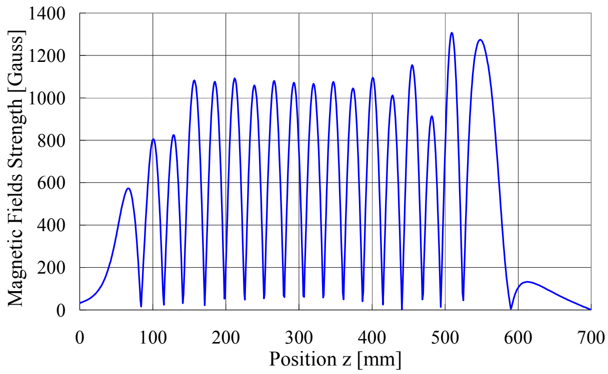

Figure 3: Magnitude of axial PPM focusing field strength for S-band klystron

3.2 ELECTRON GUN

Symons reported the relationship of an RF efficiency η and beam perveance P ($I/V^{3/2}$) can be expressed as below: [5]

$$\eta(\%) = 90 - 20 \times P(\mu perv.)$$

The microperveance for our S-band klystrons is chosen approximately 2. Expected RF efficiency is 50% at the maximum. To compromise requirements of high voltage insulation and also higher efficiency, the operating cathode voltage was decided to be 160kV for the S-band 7.5 MW E3772 klystron.

Figure 4 shows the result of D-GUN simulation for the C-band 7 MW E3773 klystron. It shows that the beam ripple is less than 5%.

In S-band case, the convergence ratio of the electron beam is smaller than the C-band tube due to the larger beam diameter. There is no problem that the PPM focusing system can replace as the solenoid focusing system at S-band tube.

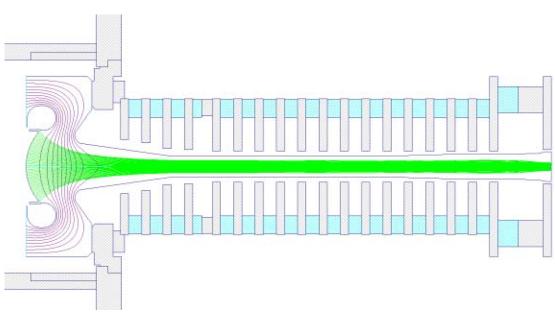

Figure 4: D-GUN simulation of C-band 7MW PPM klystron

As mentioned in the reference, the gun surface gradients must be limited to be about 250kV/cm in pulse operation. [6] Results from simulation indicated that the surface gradients are less than 186kV/cm at the cathode voltage of 160kV.

3.3 CONSIDERRATION TO INSTABILITY

If a feed back loop is formed inside the klystron due to the back streaming beam, we should consider to the spurious oscillation problem. When the klystron voltage gain and feedback coefficient is larger than unity, and the phase is zero or integral times of 2π, the spurious oscillation will occur [7]. In S-band klystron with the 50dB gain case, when the beam current exceeds 250A, we estimated that there are some risks that the spurious oscillation might occur. When we will design S-band PPM klystron that can generate an output power more than 20MW, it is necessary to more carefully considerations to the instability.

4 CONCLUSION

We discuss the availability of the S-band PPM focused klystron that is used for medical and industrial linacs. It is possible that the PPM focused klystron can replace as the solenoid focused tube. It is not necessary to change the modulator. If a PMM focused klystron is used, the size of the accelerator system is substantially reduced. The majority of medical and industrial linacs use frequencies of S-band range. There are many advantages to using higher frequency (C or X-band) for the compact accelerator systems. We are now developing C-band 7MW PPM klystron for the linac of SCSS project. [8]

5 REFERENCES

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