DEVELOPMENT OF C-BAND MULTI BEAM SUB-BOOSTER KLYSTRON

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Abstract

A C-band small multi beam klystron (MBK) has been under development. It is designed for the sub-booster klystron which is required to drive multiple 50 MW C-band klystrons for the SuperKEKB injector upgrade plan. The designed output power is 150 kW in case of the applied voltage of 25 kV which is suitable for the existing pulse modulator for the S-band sub-booster klystron. At this operating condition, the designed micro-perveances of the total and the each beamlet are 2.0 and 0.25 respectively. The design overview will be presented.

MOTIVATION

KEKB attained the highest luminosity of 1.7×10^{34} $cm^{-2}s^{-1}$ in the world. KEKB consists of an 8 GeV electron ring (HER) and a 3.5 GeV positron ring (LER). The KEKB Injector linac [1] has provided 8 GeV electrons and 3.5 GeV positrons to inject those rings directly.

To aim for a ten-times higher luminosity, the SuperKEKB project [2] is under consideration as an upgrade of KEKB. In the SuperKEKB project, energy exchange of beams has an important role to escape the influence of electron clouds for the positron ring (LER). To exchange the beam energy of the LER and the HER, the energy of a positron beam has to be raised from 3.5 GeV to 8 GeV. However the acceleration length after generating positrons is restricted because a positron is a secondary particle. One of solutions is to double an acceleration field. Thus the C-band (5712 MHz) accelerating unit [3] has been developed to obtain the higher acceleration field over 40 MV/m.

A C-band accelerating unit consists of one 50 MW klystron and four accelerating structures. In the present KEKB Injector linac, eight S-band klystrons, which is called as a sector, are driven by one 80 kW sub-booster klystron and its low RF power circuits. In case of the C-band acceleration, one sector consists of 16 accelerating units because a C-band accelerating unit has only half length compared with the present S-band accelerating unit. Thus the C-band sub-booster klystron has to drive 16 high power klystrons. The required output power of the sub-booster klystron becomes 150 kW considering the power loss of the waveguide.

DESIGN OUTLINE

Assuming the lower expected efficiency of 0.8 - 0.2 μP which is obtained from the general experience, the relation between the applied high voltage and the RF output power satisfies the following equation.

$$\mu P\left(0.8-0.2\mu P\right) = Pout/\mathrm{Vk}^{2.5}\times10^{6} \qquad (1)$$

Figure 1 shows the micro perveance (μP) and the expected efficiency versus the applied high voltage in case of the required RF output power (Pout) of 150 kW.

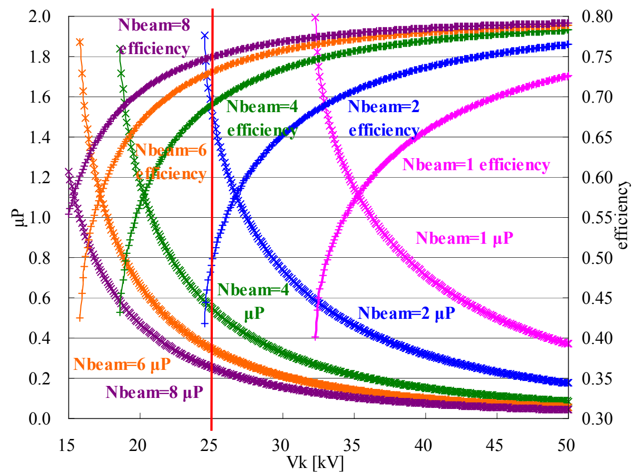

Figure 1: Micro perveance (μP) and Expected efficiency versus the applied high voltage in case of the required RF output power (Pout) of 150 kW.

The existing pulse modulator for the S-band sub-booster klystron is planned to use for the newly developed C-band sub-booster klystron. The operating high voltage (Vk) of the pulse modulator is 25 kV. From figure 1, more than 4 beamlets are required to obtain the RF output power of 150 kW.

Table 1 shows the klystron parameters corresponding to the number of beamlets.

The difficulty to construct the multi-beam klystron is the insertion of some iron plates to make the magnetic field parallel, even though the convergent electron gun is used. To avoid this difficulty, the immersed flow electron gun is chosen. Thus 8 beamlets are chosen for this C-band sub-booster klystron to make the cathode within the limited cathode beam loading (6 A/cm^2).

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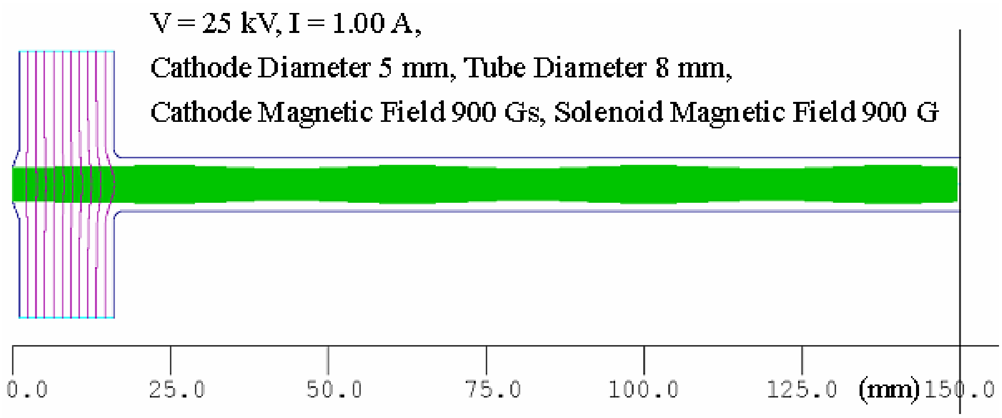

Figure 2: The beam trajectory of the electron gun.

Table 1: Klystron parameters corresponding to the number of beamlets.

Parameter	Value				
Frequency (MHz)	5712	5712	5712	5712	5712
Output Power (kW)	80	150	150	150	150
Beam Voltage (kV)	25	25	25	25	25
Beam Current (A)	7.88	6.11	2.17	1.37	1.00
μP per beamlet	1.98	1.55	0.55	0.35	0.25
Efficiency (%)	40.4	49.1	69.0	73.1	74.9
Number of Beams	1	2	4	6	8
Cathode Loading (A/cm^2)	6.00	6.00	6.00	6.00	6.00
Cathode Area (cm^2)	1.31	1.02	0.36	0.23	0.17

ELECTRON GUN

Figure 2 shows the beam trajectory of the electron gun determined by the simulation code DGUN [4]. Although the beam trajectory has periodic bulges in the immersed flow, the required magnetic field for enough small beam radius is 900 Gauss. The cathode beam loading is 5 A/cm^2 which is enough low for long life time in such a short pulsed klystron.

INTERACTION CAVITIES

The designed klystron consists of 6 interaction cavities. Those cavities are common for the 8 beams. Although the structure of cavities has to consider the 3D geometrical shape, the axial symmetric model is enough for the beam simulation after some translation to the electrical parameters: R/Q, Q, the frequency detuning and the distance of gaps etc. The parameters of those interaction cavities were optimized using the 1D and 2.5D PIC simulation code. Figure 3 shows the result of the 1D simulation. The simulations show that the efficiency is close to 60 % at a drive power of 5 W. The efficiency becomes lower than the ideal expected luminosity since the beam pipe radius comparatively becomes large due to the immersed flow. Thus the expected output RF power is 120 kW which is enough for the C-band system.

According to the optimization of the parameters of cavities, the 3D geometrical shape was determined by 3D electromagnetic wave solver. Figure 4 is 3-dimensional shape of the interaction cavity(left) and the output cavity(right).

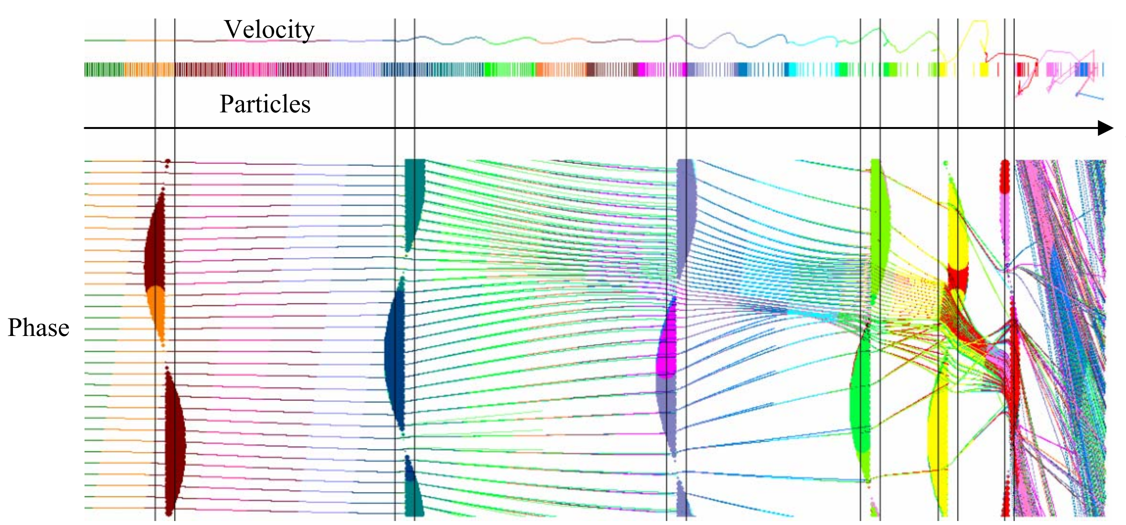

Figure 3: The result of the 1D simulation.

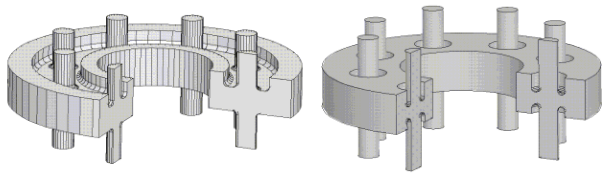

Figure 4: The interaction cavity(left) and the output cavity(right).

MECHANICAL DESIGN

Figure 3 shows the mechanical design of the klystron using the 3D CAD. Before testing the klystron, we will test the electron gun itself. Figure 4 shows the beam test tube to test the electron gun. The 8-beam cathode was made of Toshiba Electron Tubes & Devices Co., Ltd. In this design, the common type heater was adopted for easy fabrication.

CONCLUSION

The design of the C-band sub-booster klystron is completed and currently under construction. The klystron has 8 beamlets and its output power is over 120 kW expected by the simulation. We will test the klystron performance after the beam test tube will be tested. If we successed to operate this klystron, we will proceed to manifacture the L-band multi beam klystron for the ILC project by using the same design procedure.

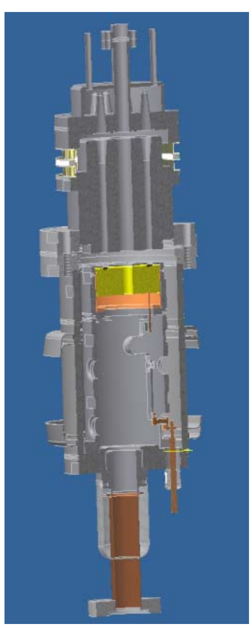

Figure 5: Design of the Beam Test Tube.

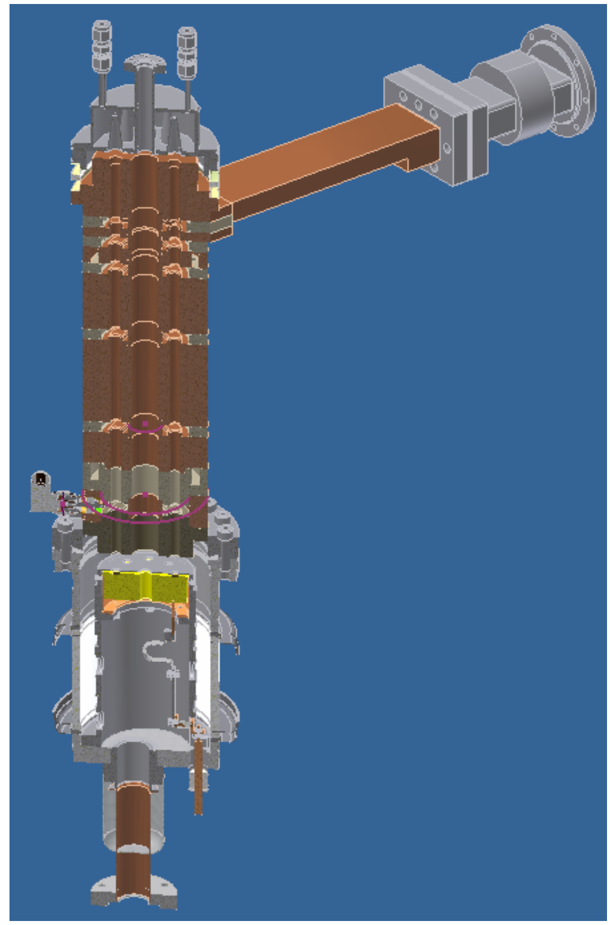

Figure 6: Mechanical design of the klystron.

REFERENCES

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