DESIGN OF CONFINED FLOW MULTIPLE BEAM GUNS WITH COMPRESSION FOR POWERFUL KLYSTRONS

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Abstract

This paper describes the design of a confined flow multiple beam gun that provides 2 times radial compression of the generated multiple beam. The subsequent focusing of the compressed beam is carried out in a solenoid magnetic field that corresponds to the 1.5-2 times the Brillouin field. The formed multiple beam has a ring structure and consists of 24 individual beamlets. As a possible applications of such a gun we consider a low-voltage (60 kV) 10 MW L-band MBK for the ILC (International Linear Collider) and also a 10, 40 MW X-band MBK to support accelerating technologies now under development at KEK. The results of the 3D simulation of the gun for these cases are presented.

INTRODUCTION

Multiple beam guns with compression are sometimes named as double convergent guns, which implies the convergence of the entire multiple beam to the device axis and also the convergence of individual beamlets around their own axis. The basic advantage of such guns is that their cathode loading can be considerably reduced in comparison with linear guns having an identical diameter of the formed multiple beam. Consequently, the use of such guns in klystrons allows the power and/or the life time of these devices to be increased; further in some cases the device cost is considerably reduced.

Another important factor for powerful klystrons is the confined flow focusing that, as is well known, considerably simplifies high power operations. Here, one can draw an analogy with the conventional one-beam klystrons. In a majority of them the confined flow focusing is used and the typical value of the solenoid magnetic field is 1.5-2 times Brillouin field. Generally a strong magnetic field is more preferable for the klystron operation, for example, for the achievement of high efficiency or high average RF power, however, the cost of magnet increases in this case and becomes high. On the contrary, if the focusing magnetic field is less than ~1.5 times Brillouin field, the magnet cost is kept relatively low, but a number of problems can appear in the working of the klystron. Thus, the focusing field that is equal to 1.5-2 times Brillouin field can be considered as the practical optimum for the powerful one-beam klystrons and it would be natural to use the same conditions for multiple beam focusing.

From the facts pointed out above, it is evident that the combination of beam compression and confined flow focusing in the multiple beam gun appears very attractive for use in the powerful MBKs. However, it is rather difficult to specify any real solution to this problem at present.

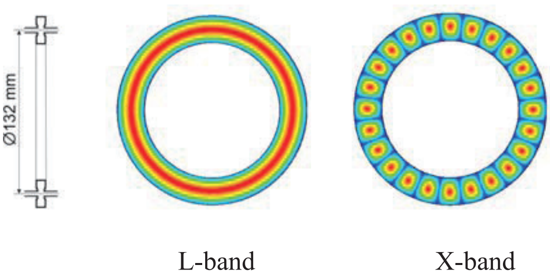

Figure 1. *RF field distribution in the ring shaped cavity for the L- and X-band klystrons.*

In this work the gun design is presented that provides 2 times radial compression of the generated multiple beam. The subsequent focusing of the compressed beam is carried out in a solenoid magnetic field, that is equivalent to the 1.5-2 times the Brillouin field. The formed multiple beam has a ring structure and consists of 24 individual beamlets. The beamlets are arranged in a circle with a diameter of 132 mm at regular intervals. We consider a few possible versions of such gun for use in the following devices.

1. A low-voltage (60 kV) 10 MW L-band MBK for the ILC (International Linear Collider).
2. A 10, 40 MW X-band MBK to support accelerating technologies now under development at KEK (Japan).

Here, we offer to the use of the ring-shaped cavities, that operate in the fundamental mode for the L-band klystron case and high order mode $TM_{12,1,0}$ for X-band (see Fig.1).

ELECTRON-OPTICAL SYSTEM

An outline of the multiple beam gun and its essential design parameters for the cases specified above are shown in Fig. 2 and Table 1. Initially the multiple beam is formed as radially convergent in the spherical-type gun. The magnetic field in the gun is shaped by two common cathode coils and also by the spherical magnetic screen (shield) located behind the anode of the gun. The beam compression is carried out using a special magnetic lens, named as compression lens. While passing through this lens, the beam is compressed and simultaneously transformed from a radially convergent beam to a linear beam. The individual beamlets rotate slightly around the general device axis while they move inside the compression lens. The turning angle is relatively small and equals ~5-7°. However, at the lens outlet, the beamlets become strictly parallel to the device axis and move further along individual drift tubes.

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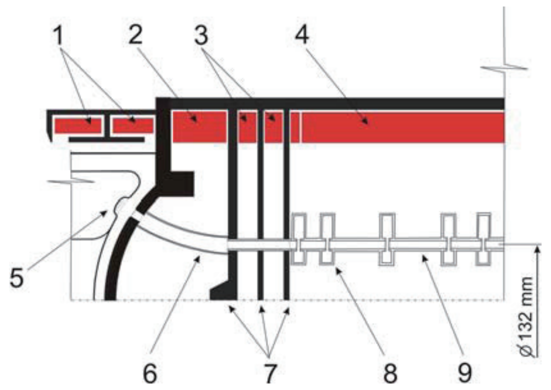

1. Cathode coils; 2. Compression lens coil; 3. Matching lens coils; 4. Solenoid; 5. Cathode; 6. Coaxial structure for beamlets transport; 7. Magnetic shield (material: steel); 8. Klystron cavity; 9.Individual drift tube for beamlet

Figure 2. *Outline* of *the confined flow multiple beam gun with a compression.*

The compression lens can focus a multiple beam that is formed at different voltages of the cathode. In this case the lens magnetic field should be adjusted depending on the cathode voltage that can be accomplished by the appropriate selection of the lens coil current.

For the beamlets to match with the solenoid magnetic field, two magnetic lenses are used. The lenses are designed in a manner similar to the solenoid sister-coils and are separated by flat steel screens with the holes for beamlets. The use of two matching lenses results in the high adaptability of the optical system, and it allows the matching beamlets for a wide range of solenoid fields and magnetic fields at the cathode. Different variations of the magnetic field of the compression lens also can be compensated by a couple of matching lenses. Approximate ranges of magnetic field changes at the cathode and in the solenoid can be specified as follows.

$\boldsymbol{B_{cathode} \sim 0 - 40}$ **Gs;** $\boldsymbol{B_{solenoid} \sim 800 - 2400}$ **Gs**

For these ranges and for the chosen design of the magnetic system the equilibrium size (diameter) of a beamlet in the solenoid can vary within of ~3 - 9 mm

	10 MW L-band	10 MW X-band	40 MW X-band
Voltage (kV)	60	60	120
Total current (A)	265	327	750
Cathode loading (A/cm^2)	2.4	3	6.6
Maximal electrical field at the gun (kV/mm)	4.8	5.5	9.6
Beam power (MW)	15.9	19.6	90

Table 1. *Essential design parameters of the multiple beam guns for different cases.*

which allows the use of a multiple beam for both L-band and X-band klystrons.

It should be pointed out that the multiple beam with controlled (changeable) beamlet diameters allows the realization of additional and effective "fine tuning" of the klystron, for example, it optimizes the RF efficiency, the current passage in the dynamic mode and suppresses spurious oscillation if any etc.

MULTIPLE BEAM MODELING

For the gun modeling we used the 3D stationary code GUN3D which is currently under development at PTC of LPI (Protvino, Russia). The general scheme of calculation, which is used in GUN3D, comprises the calculation of both 3D electrical fields with due regard to the space charge and the 3D self magnetic field of a beam. The self magnetic field is calculated with the assumption that the conductivity of the metallic gun electrodes is ideal , i.e. it is assumed, that during the current pulse the field does not penetrate through metal. (the skin depth $\delta = 0$ and corresponding borderline condition for field $B_n = 0$). The external magnetic field is specified in the form of a mesh, which is based on the data obtained by using the ANSYS.

An example of the GUN3D code modeling is shown in Fig.3. Further, in Fig. 4, the calculated cross section of the individual beamlet in the compression lens outlet is illustrated. We can observe that both the 3D beamlet perturbations and the beamlet displacement about the optical axis are sufficiently small. Moreover, the angle between the central beamlet trajectory and an optical

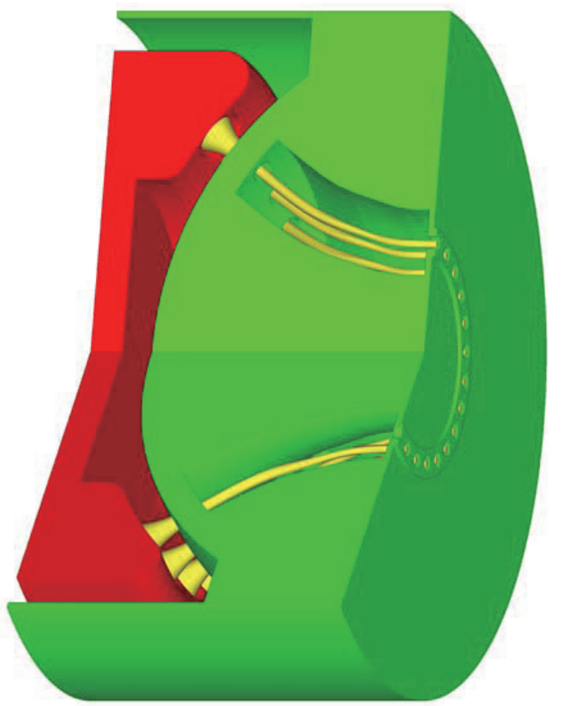

Figure 3. *Example of the multiple beam gun modeling by using the GUN3D code (40 MW X-band klystron case)*

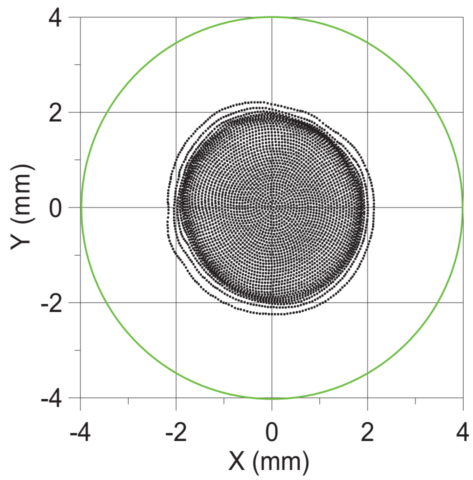

Figure 4. *Cross-section of the individual beamlet at the compression lens outlet (40MW X-band klystron case).*

axis, obtained from the calculations, as a rule, does not exceed 1-1.5°. Therefore, the further beamlet movement inside both the matching lenses and solenoid can be being considered to be two-dimensional. Accordingly, faster 2D codes can be used in the calculation, for instance, in order to solve the problem of beamlets matching with a solenoid. The development of a 2D model is also very important for the simulation of the klystron dynamic mode. An example of such modeling by using the DGUN code [1] is shown in Fig. 5. The region of 3D beamlet movement (compression lens region) and the magnetic field inside it are replaced here by their 2D equivalents. The equivalent 2D magnetic field is chosen so that its value on axis is close to the real longitudinal magnetic field directed along the central 3D beamlet trajectory.

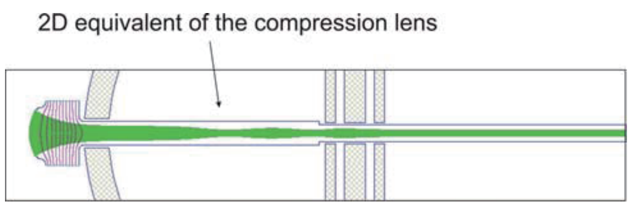

Figure 5. *An example of 2D modeling by using the DGUN code.*

GUN ADJUSTMENT

An important feature of the presented gun design is that it is simple to correct beamlet displacements about their optical axes at the compression lens outlet. In practice, the appearance of displacements can be caused, for example, by small errors or discrepancies in the manufacture of both the gun and magnetic system. In order to correct these displacements, the gap between the magnetic pole and the flat steel screen in the compression lens can be made variable (see Fig. 6). Moreover, the gap dimension and also lens current should be considered as

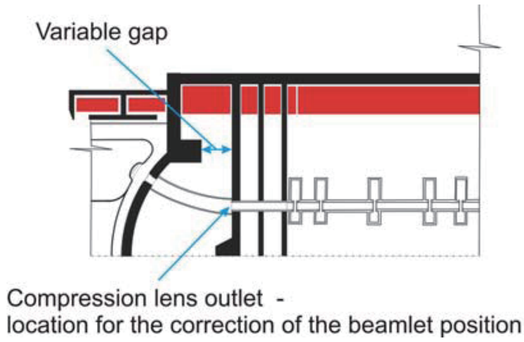

Figure 6. *Displacements correction scheme.*

parameters of adjustment. The position of the center of the individual beamlet at the lens outlet which depends on these parameters is shown in Fig. 7. Thus, in particular, it follows that any random displacement can be easy compensated.

It is significant to note that the method of correction described above is not the only one. For example, the same effect can be obtained if the thickness of a pole of the compression lens is varied. Therefore, in general we can assert that the effect of correction can be obtained by the selection of an appropriate pole shape for the compression lens.

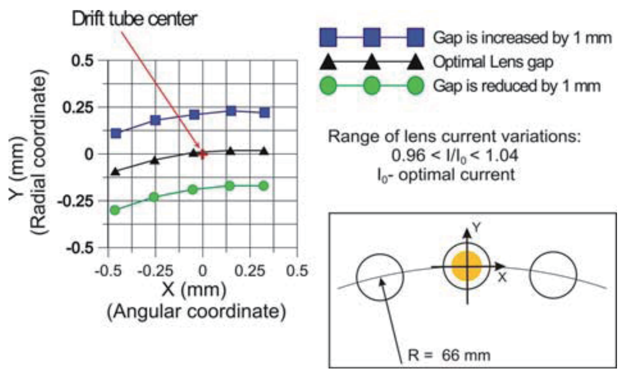

Figure 7. *Position of the beamlet center at the compression lens outlet depending on lens current and lens gap size (10 MW L-band klystron case).*

CONCLUSION

Thus, the described design of the multiple beam gun with compression provides sufficiently high quality beamlets, and it can be used for the development of both powerful L-band and X-band klystrons. At the same time the specified method of the gun adjustment considerably simplifies practical realization of the presented gun.

REFERENCES

[1] A. Larionov, K. Ouglekov, "DGUN-code for simulation of intensive axial-symmetric electron beams", 6th International Computational Accelerator Physics Conference, TU Darmstadt, Germany, 2000, p. 172.