NEW SCHEME FOR MAGNETIC COMPRESSION OF THE MULTIPLE BEAM AT THE POWERFUL MULTI-BEAM KLYSTRON

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Abstract

This paper describes the design of the optical system of the powerful multi-beam klystron (MBK) that provides approximately twofold radial compression of the generated multiple beam. The basic advantage of this design is that the multiple beam is formed in the flat-type gun. The compression of the multiple beam and its matching with a solenoid magnetic field are also carried out, use being made of the set of simple magnetic lenses. Lenses are designed in form of the solenoid sister-coils and separated by the flat iron screens with the apertures for individual beamlets.

The optical system in question may be applied in a low-voltage (60 kV) 10 MW L-band MBK for the ILC (International Linear Collider) as well as in a 10 MW X-band MBK to support the accelerating technologies being now under development at KEK (Japan).

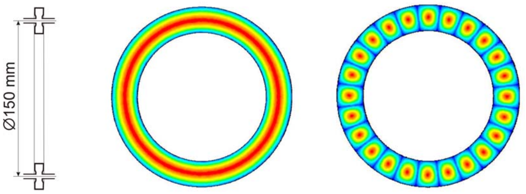
Herein are presented the results of the 3D simulation of the multiple beam optics for the mentioned above applications.

INTRODUCTION

The basic advantage of the multiple beams with compression is that cathode loading in such systems can be considerably reduced. Consequently, the use of such schemes in the multiple beam 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 magnitude 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, to achieve high efficiency or high average RF power. However, the cost of magnet increases in this case gets too 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 course of the klystron operation. 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 multiple beam compression and confined flow focusing appears very attractive for application in the powerful MBKs. However, it is rather difficult to specify any practical solution to this problem at present.



L-band X-band

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

In our early projects we studied the design of a spherical type multiple beam gun that provides a twofold radial compression of the generated multiple beam [1,2]. The multiple beam we formed had a ring structure and consisted of 24 individual beamlets. The subsequent focusing of the compressed beam was carried out in a solenoid magnetic field that corresponded to the 1.5-2 times the Brillouin field.

In this work in order to simplify MBK design and also to reduce the MBK cost we consider a new scheme for magnetic compression of the multiple beam in klystron. The basic merit of this scheme is that the multiple beam is formed in a flat-type gun. The compression of the multiple beam and its matching with a solenoid magnetic field are also carried out with use being made of the set of simple magnetic lenses. Lenses are designed in form of the solenoid sister-coils and separated by the flat iron screens with the apertures for individual beamlets.

We consider two possible applications of the optical system in the following devices.

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

Herein, we assume application of the ring-shaped cavities, operating 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 electron-optical system and its essential design parameters for the cases specified above

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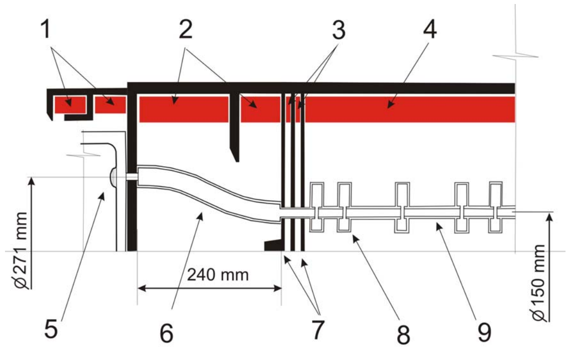

1. Cathode coils; 2. Compression lens coil; 3. Matching lens coils; 4. Solenoid; 5. Cathode; 6. Coaxial structure for beamlets transport; 7. Magnetic shield (material: steel); 8. Klystron cavity; 9.Individual drift tube for beamlet

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

are shown in Fig. 2 and Table 1. Initially the multiple beam is formed in the flat-type gun. The magnetic field inside the gun is shaped by two common cathode coils as well as by the flat magnetic screen (shield) located behind the anode of the gun. The beam compression is carried out with use of a special magnetic lens, named as a compression lens. While passing through this lens, the multiple beam is compressed and simultaneously rotate slightly around the general device axis. At the lens outlet, rotation of the multiple beam is stopped, also individual beamlets become strictly parallel to the device axis and move further along individual drift tubes.

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. The adjustment can be accomplished by the appropriate selection of the lens coils currents.

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

	10 MW L-band	10 MW X-band
Voltage (kV)	60	60
Total current (A)	265	327
Cathode loading (A/cm^2)	2.6	3
Maximal electrical field at the gun (kV/mm)	4.8	5.5
Beam power (MW)	15.9	19.6

For the beamlets to match with the solenoid magnetic field, two magnetic lenses are used. The lenses are designed in form which is similar to the solenoid sister-coils and are separated by flat steel screens with the apertures for beamlets. The application of two matching lenses results in the high adaptability of the optical system, and it enables to match beamlets in 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 changes in the ranges of magnetic field at the cathode and in the solenoid can be specified as follows.

$$B_{cathode} \sim 0\text{ -}40\ Gs; \quad B_{solenoid} \sim 800\text{ -}2400\ Gs$$

For these ranges and for the selected design of the magnetic system the equilibrium size (diameter) of a beamlet in the solenoid can vary within of ~3 - 9 mm which allows for 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 for 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 there are any. It can also provide solving other problems to occur.

MULTIPLE BEAM MODELING

For the beam 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 in case of pulse current the field does not penetrate through metal. (the

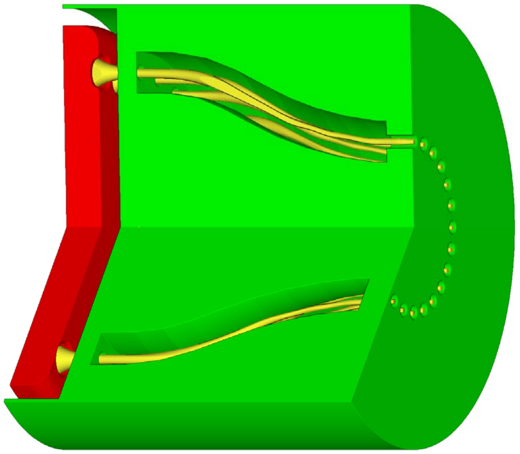

Figure 3. Example of the multiple beam gun modeling by using the GUN3D code

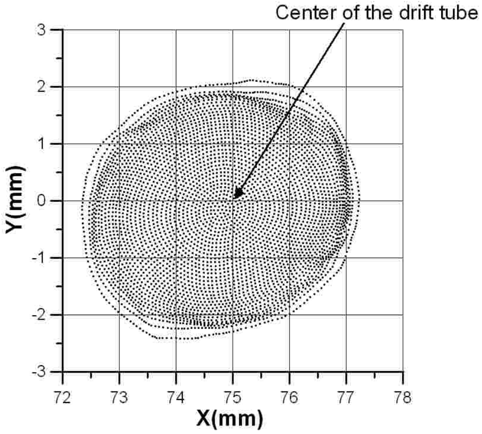

Figure 4. Cross-section of the individual beamlet at the compression lens outlet.

skin depth $\delta = 0$ and corresponding borderline condition for field $B_n = 0$).

The external magnetic field is specified in the form of a finite-element 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 in relation to the optical axis are sufficiently small. Moreover, the angle between the central beamlet trajectory and the optical axis, obtained from the calculations, as a rule, does not exceed 2-2.5°. Therefore, the further beamlet movement inside both the matching lenses and solenoid can be considered as a two-dimensional. Accordingly, faster 2D codes can be used in the calculation, for instance, in order to solve the problem of matching the beamlets with a solenoid.

BEAMLETS DISPLACEMENT AT THE PULSE FRONT

The problem of beamlets displacements in course of the front of voltage pulse is considered common for all optical systems where a 3D movement of a beamlet occurs. The phenomenon can cause beam losses under low voltage and, as a consequence, limitation of maximal MBK power.

In case of the X-band MBK, to achieve high efficiency, the required diameter of the beamlet drift pipes should be 1.5-2.5 times smaller compared to L-band MBK case. Therefore, it results in more severe technical requirements concerning beamlets displacement.

It is worth mentioning, that the presented optical scheme possesses smaller beamlets displacements at the pulse front compared to the previous design [1,2] with the spherical type multiple beam gun (see Fig.5). To account for that is the fact is that deviation of the beamlet trajectory from the magnetic force line inside the compression lens is compensated. In other words, at first the beamlet goes apart from a magnetic force line but subsequently it starts to come back. Such effect of compensation is entirely absent in the mentioned design with the spherical type multiple beam gun. Therefore beamlet deviation from magnetic force line is greater in this case. As the beamlet trajectory under a low voltage becomes near to the magnetic force line, we can assume, that beamlet displacement at the pulse front is predetermined by the magnitude of the beam deviation from magnetic force line.

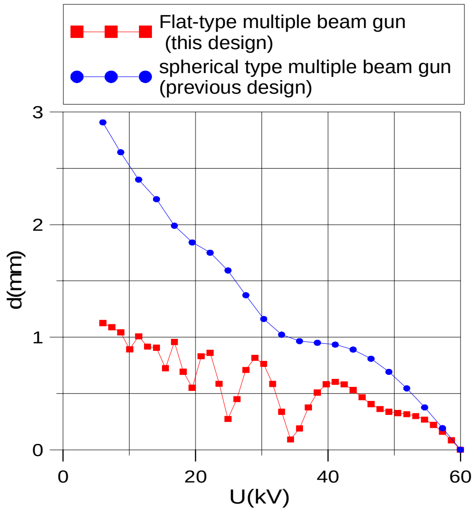

Figure5. Beamlet displacement at the compression lens outlet depending on the voltage at pulse front.

CONCLUSION

Thus, the presented scheme for magnetic compression of the multiple beam provides admissible quality of the formed beamlets, and it can be used for the development of both powerful L-band and X-band klystrons. The advantages of this scheme are technical simplicity for the realization and relatively low beamlet displacements at the voltage pulse front.

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REFERENCES

[1] A. Larionov, S. Fukuda, “Design of the confined flow multiple beam guns with a compression for L and X-band powerful klystrons”, Proceedings of the Eighth International Vacuum Electronics Conference, IVEC 2007, Kitakyushu, Japan, May 15-17, 2007, p. 381.

[2] A. Larionov, S. Fukuda, “Design of confined flow multiple beam guns with compression for powerful klystrons”, Proceeding of 4th Conference of Particle Accelerator Society of Japan / 31st Linear Accelerator Meeting in Japan, August 1-3, 2007, Wako, Japan.