Study of Radial Position of pole Piece Aperture in Focusing of Multibeam Electron Gun

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Abstract. A four beam electron gun has been designed for multi-beam klystron using commercially available software OPERA 3D and the optimized beam focusing has been again examined through CST particle studio. This paper represents the effect of radial position of aperture in a pole piece in focusing of multi-beam electron gun. The operating voltage of electron gun is 4 kV with total beam current of 256 (64x4) mA and beam perveance of 1.01 µP which is equally divided among all the beamlets.

1. Introduction
Today, the microwave tubes designer faces a number of challenges like high operating voltage, narrow bandwidth and more weight. The basic idea of multi-beam electron gun is an attempt to increase the beam current without increasing the cathode loading. The multi-beam klystrons (MBKs) are the only microwave amplifiers that fulfill the most of present demand of users, such as high power, high efficiency, large bandwidth, low noise and low-voltage operation, as compared to the conventional single-beam klystrons. In addition, the reduced operating voltage significantly decreases the cost of the power supply system and reduces the device length thereby making the device more compact. Due to these features MBK is used for ground-based, airborne and space-based radars, radio-communication and high energy particle accelerators [1]-[7].

In an MBK each beamlet propagates along its own individual path through the RF section consisting of two or more cavity resonators. The most important advantage of an MBK is that the current and perveance per beamlet are low while total current and perveance remain high in this device. For higher electronic efficiency and gain of device bunching should be more, which can be achieved by low perveance per beamlet. Further, the overall higher perveance allows a lower voltage operation yielding higher beam power and RF power as compared to conventional single beam klystron. In addition, the reduced operating voltage significantly decreases the cost of the power supply system and reduces the device length thereby making the device more compact [2], [8]. The schematic of multi-beam electron gun with pole piece position is shown in figure 1 and the gun design parameters of multi-beam electron gun are shown in Table 1.
2. Electron Gun Design and Effect of radial position of Pole Piece Aperture in Beam Focusing

Using OPERA 3D [9] code a confined flow multi-beam electron gun has been simulated with three different PCDs (pitch circle diameter) at 15 mm, 20 mm, and 25 mm at an angular distance of 90 degrees from each other to study the scalloping in off-axis beams relative to solenoid axis as shown in figure 2.

A study related to the effect of radial position of apertures in pole piece on beam focusing has been carried out using OPERA 3D and CST particle studio [10]. A four beam electron gun (Table I) has been simulated by keeping four beamlets at different PCDs and having a common solenoid focusing with optimum axial magnetic field $B_z$ as 1200 Gauss. This field has been optimized for minimum beam scalloping after a number of iterations.

Detailed studies by keeping apertures in pole piece at three different PCDs (i.e. 15 mm, 20 mm and 25 mm) have revealed that apertures at smaller PCDs yield better beam focusing (less ripples) in comparison to the apertures at higher PCDs. This is corresponding to the fact that in case of apertures at smaller PCDs the electric field at cathodes is higher and transverse magnetic field at aperture is smaller. It has also been observed that for a common solenoid smaller the PCD better is the focusing. Beam scalloping is minimum at 15 mm PCD (Figure 3) in comparison to 20 mm PCD (Figure 4). The 25 mm PCD shows no beam focusing is possible using the same solenoid as the beam transmission through the tunnel is zero as shown in Fig. 5. This study shows that a maximum allowed PCD for a specific solenoid the clearance between solenoid inner diameter and the maximum PCD should be more than 40 % in order to achieve desired focusing with minimum scalloping. The same cases (Figures. 3, 4 and 5) have also been simulated using CST particle studio. The simulated results from both OPERA and CST codes are in good agreement and shown in Table 2.

### Table 1. Gun design parameters

| Parameter          | Value        |
|--------------------|--------------|
| Cathode voltage    | 4 kV         |
| No. of beamlets    | 4            |
| Total beam current | 256 mA       |
| Total beam perveance | 1.01 µP   |
| Individual beam perveance | 0.252 µP |
| Cathode diameter   | 14.4 mm      |
| Cathode loading    | 0.85 A/cm²  |
| Beam waist radius  | 0.45 mm      |
| Beam throw         | 14 mm        |

![Figure 1. Schematic of multi-beam stick tube](image1)

![Figure 2. Schematic of a multiple-beam electron gun on different PCD](image2)
Figure 3. Electron trajectories at 15 mm PCD

Figure 4. Electron trajectories at 20 mm PCD

Figure 5. Electron trajectories at 25 mm PCD
Table 2. Comparison between OPERA-3D and CST-3D Simulated Beam Parameters

| Parameters                  | OPERA-3D (PCD (mm)) | CST (PCD (mm)) |
|-----------------------------|---------------------|----------------|
| Beam Current (mA)           | 256 (64x4)          | 240 (60x4)    |
| Beam Throw (mm)             | 13                  | 13            |
| Beam Waist Radius (mm)      | 0.35                | 0.36          |

3. Conclusion
This paper represents that a maximum allowed PCD for a specific solenoid, the clearance between solenoid inner diameter and the maximum PCD should be more than 40% in order to achieve desired focusing with minimum scalloping. The simulated results from both the codes OPERA-3D and CST particle studio are in good agreement as summarized in Table 2.

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References
[1] Korolyov A N, Gelvich E A, Zhary Y V, Zakurdayev A D, and Poognin V I, Jun. 2004 *IEEE Trans. Plasma Sci.*, *32*, 3, 1109.
[2] Nguyen K T, Abe D K, Pershing D E, Levush B, Wright E L, Bohlen H, Staprans A, Zitelli L, Smithe D, Pasour J A, Vlasov A N, Antonsen T M, Jr., Eppley K, and Petillo J J, Jun. 2004, *IEEE Trans. Plasma Sci.*, *32* 3 1119
[3] Abe D K, Pershing D E, Nguyen K T, Myers R E, Wood F N, and Levush B, May 2007 *IEEE Trans. Electron Devices*, 54 5 1253
[4] Gelvich E A, Borisov L M, Zhary Y V, Zakurdayev A D, Pobedonostsev A S, and Poognin V I, Jan. 1993, *IEEE Trans. Microwave Theory Tech.*, 41 15
[5] Korolyov A N, Gelvich E A, Zhary Y V, Zakurdayev A D, and Poognin V I., Dec. 2001, *IEEE Trans. Electron Dev.* 48 2929
[6] Ding Y, Shen B, Shi S, Cao J, May 2005, *IEEE Trans. Electron Dev.* 52 5 889
[7] Nguyen K T, Pershing D E, Abe D K, Levush B, Wood F N, Calame J P, Pasour J A, Petillo J J, Cusick M, Cattelino M J, and Wright E L, Jun. 2004, *IEEE Trans. Plasma Sci.* 32 3 1212
[8] Gilmour A S, Jr, 2011 Boston, Artech House, Klystrons, Traveling Wave Tubes, Magnetrons, Crossed-Field Amplifiers, and Gyrotrons,
[9] Opera-3D, Cobham technical services, Vector fields software, 24 Bankside Kidlington Oxford OX5 1JE England.
[10] CST-Particle studio, User manual: 2010 version, Darmstadt, Germany.