# Simulation of Transverse Field Sweeping System with Different Modulation Waves for MW-class Gyrotron


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**Abstract:** *The transverse field sweeping system is capable of spreading electron deposited areas and reducing peak power density efficiently. In order to obtain lower peak power density further, the means of modulation wave has been employed. The effect of different modulation waves have been investigated using CST code in this paper. The simulated results indicate the triangular wave has the best performance among rectangular wave, triangular wave and cosine wave. Finally, the optimal peak power density* $106.2\ W/cm^2$ *has been obtained.*



**Keywords:** gyrotron; magnetic field sweeping system; MW-class; modulation


## I. Introduction

Gyrotron is a high power millimeter wave device which is capable of generating MW-class power output at the frequency above 100GHz [1-3]. Such a huge output power causes the difficulty in dissipating much more power of spent electrons on collector. The ability of spreading spent electron trajectory to conventional collector is limited. Therefore, the peak power density exceeds easily the tolerance of collector wall. The introduction of transverse field sweeping system is an efficient means to solve this issue. The transverse field sweeping system (TFSS) is composed of three pairs of transverse field coils and one vertical field coil. The vertical field coil is used to move the electron trajectory along the vertical axis. The transverse field coils could distort the electron trajectory forming ellipse rather than conventional circle. This behavior is due to the supplied current phase shifted of adjacent transverse field coils [4-5]. The elliptic trajectory is illustrated in Fig.1. Moreover, it's useful to modulate the supplied current of transverse filed coil. In this way, the local hot spot would be scattered to adjacent areas. The lower peak power density would be obtained at a calculated time period.

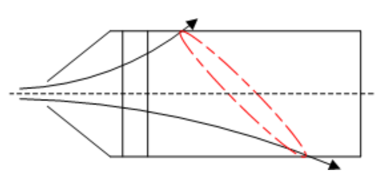
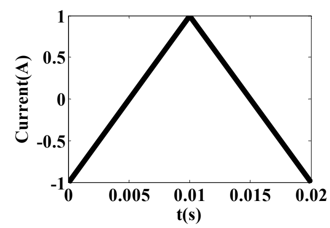


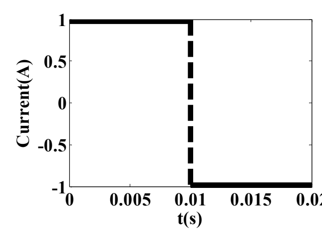
**Fig.1.** The schematic of elliptic electron trajectory with TFSS

## II. The simulation results

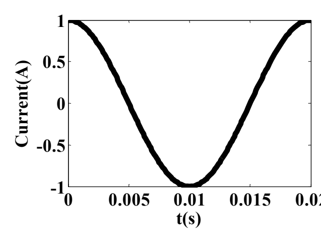
Initially, the peak power density has been reduced to $128.7\ W/cm^2$ from $482\ W/cm^2$ by means of TFSS. Obviously, the effect of TFSS is remarkable. At the same time, the spent electron deposited length increases to nearly 1100mm from 450mm which makes the size of collector become larger. For the sake of acquiring lower peak power density and making the design of collector cooling system easier, the modulation waves have been implemented to decrease peak power density further. The influence of three different modulation waves have been investigated including triangle wave, rectangular wave and cosine wave. The schematic diagrams of three modulation waves are showed in Fig.2. The simulated results are summarized in TABLE I.




(a) triangular wave




(b) rectangular wave




(c) cosine wave

**Fig.2.** The schematic diagrams of three modulation waves

**TABLE I.** The comparison of three different modulation waves with respect to modulation depth and peak power density

| Modulation Waves | Modulation Depth | Peak Power Density |
|---|---|---|
| Cosine Wave | 38.9% | 117.1 $W/cm^2$ |
| Rectangular Wave | 35.6% | 115.9 $W/cm^2$ |
| Triangular Wave | 5.6% | 106.2 $W/cm^2$ |

The comparison indicates the implement of modulation waves could reduce peak power density to a certain extent. The reductions of peak power density are 11.6 $W/cm^2$, 12.8 $W/cm^2$ and 22.5 $W/cm^2$ corresponding to cosine wave, rectangular wave and triangular wave. The triangular wave has the best performance with the maximum reduction of peak power density and the minimum modulation depth among three modulation waves. The increasing rate or decreasing rate of triangular wave are an constant which means the local hot spot could scatter to adjacent areas more homogeneously. This behavior tends to reduce peak power density efficiently. The power density distribution of triangular modulation wave along z axis is showed in Fig.3. The total deposited length of spent electron is approximately 1100mm and the distribution of power density is relatively homogeneous. The optimal modulation frequency of cosine wave in this case is 10Hz. Taking the cost of time into account, the simulation is only carried out at the modulation frequency 50Hz to rectangular wave and triangular wave. The process of optimization to modulation frequency would be performed in future working.

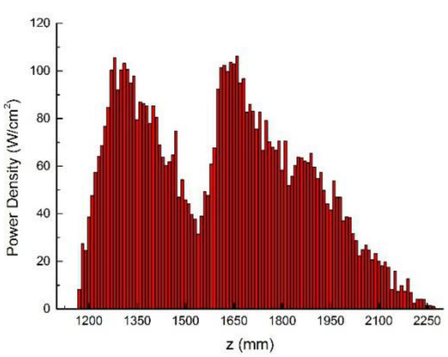



**Fig.3.** The power density distribution of triangular modulation wave

## III. Conclusion

The introduction of modulation wave could reduce peak power density to a certain extent. The influence of triangular wave on scattering local hot spot is the strongest among three modulation waves which causes the reduction of peak power density about 17.5 percent. The lower peak power density enhances the power capacity of collector. Meanwhile, it also decreases the maximum temperature of collector wall, hence, lowers the level of difficulty in design of collector cooling system. Thus, the simulated results provide specific guidance ensuring the stable and safe operation of MW-class gyrotron.

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## References

[1] K. L. Felch, B. G. Danly, H. R. Jory, K. E. Jory, K. E. Kreischer, W. Lawson, and B. Levush, "Characteristics and Applications of Fast-Wave Gyrodevices," Proceedings of the IEEE, vol. 87, no. 5, pp. 752-781, 1999.

[2] V. A. Flyagin, A. V. Gaponove, I. Petelin, and V. K. Yulpatov, "The Gyrotron," IEEE Transactions on Microwave Theory and Techniques, vol. 25, no. 6, pp. 514-521, 1977.

[3] N. Kumar, U. Singh, T. P. Singh, and A. K. Sinha, "A Review on the Applications of High Power, High Frequency Microwave Source: Gyrotron," Journal of Fusion Energy, vol. 30, no. 4, pp. 257-276, 2011.

[4] V. N. Manuilov, D. A. Smirnov, S. A. Malygin, and E. A. Soluyanova, "Numerical Simulation of the Gyrotron Collector Systems with Rotating Magnetic Field," Conf. Digest Joint 29th Int. Conf on Infrared and Millimeter Waves and 12th Int. Conf. on Terahertz Electronics, Karlsruhe, Germany, pp. 663-664, 2004.

[5] G. Dammertz, S. Illy, B. Piosczyk, M. Schmid and D. Bariou, "Collector Sweeping Systems for High Power Gyrotrons," Conf. Digest Joint 30th Int. Conf. on Infrared and Millimeter Waves and 13th Int. Conf. on Terahertz Electronics, Williamsburg, USA, pp. 293-294, 2005.