6.3: XMAGUN: An Iron Pole Piece PPM Design and Analysis FEM Code

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Abstract: *An analysis of an iron pole piece PPM code based on the Finite Element Method (FEM) for traveling-wave-tube (TWT) design is presented. The XMAGUN was developed to determine the axial and radial magnetic fields inside such devices. During simulations, the outer pole piece radius was varied and, as a result, it was obtained a growth of the axial peak magnetic field value when the outer pole piece radius was reduced. This behavior was observed when the outer pole piece radius ranged 8.7 mm - 6.3 mm. The axial magnetic field peaks obtained by the XMAGUN were compared with the analytically calculated and the FEM commercial code ANSYS and good agreement was observed.*

Keywords: FEM; focusing; pole piece; PPM; TWT.

Introduction

To predict the electron beam trajectories in linear microwave devices, a computational code is under development by the authors. The first suite developed was XMGUN, an electron gun code [1]. For focusing beams, PPM structures are widely used due to theirs reduced weight and no electric power consumption when compared to a solenoid structure [2].

The seminal work of Chang *et al.* [3] presented a design guide based on an infinitely long PPM structure, but neglecting a flux path in the air gap that was later incorporated in the work of Sterzer [4]. Although that method is accurate, it is not valid for some practical PPM structures. Recently, practical PPM models were successfully studied by Santra *et al.* [5], presented in Fig. 1, where the magnetic field was analytically established but for an infinite PPM structure. At all cases studied, the determination of the magnetic field peak is achieved by the computation of the magnetic circuit permeances of the PPM structure with pole piece.

To analyze the beam transport, a second suite, called XMAGUN has been developed, tested and integrated to the main code. In the XMAGUN, the magnetic field is obtained using the FEM approach associated to the variational method for the magnetic vector potential. Additionally, an indexed sparse matrix storage associated to the conjugate gradient method solver scheme was also developed.

In this work, using XMAGUN, the axial and radial magnetic fields are completely determined in a PPM structure, with five permanent magnets and six iron pole pieces. Some results are presented, and the axial magnetic field peak in the axis at the center of the PPM structure modeled is compared to those presented by Santra *et al.*, using ANSYS [6] and the analytical one [5].

The first part of this work presents the main characteristics of the PPM structure model used in simulations. The second part describes the most relevant results obtained and finally, the conclusion.

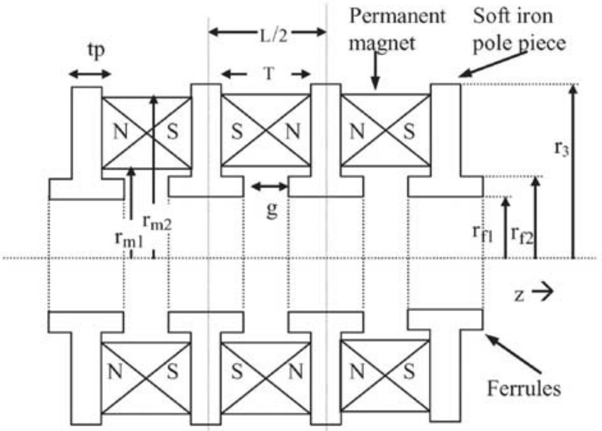

Figure 1 – PPM parameters used on the XMAGUN simulations: magnet inner radius $\mathbf{r_{m1}}$; magnet outer radius $\mathbf{r_{m2}}$; magnet thickness **T**; pole piece inner radius $\mathbf{r_{f1}}$; ferrule outer radius $\mathbf{r_{f2}}$; pole piece outer radius $\mathbf{r_3}$; pole piece thickness $\mathbf{t_p}$; gap length **g**; half magnet period **L/2**.

The PPM model

The PPM simulations were conducted, using the parameters as indicated in Table 1. The soft-iron was modeled assuming a relative permeability of 5000. A remanence of 0.85 T was used to model the permanent magnets. The axial and radial boundaries were typically five times the pole piece outer radius to emulate a far field boundary. On most simulations over 20k nodes and 40k elements were used to model the PPM and the pole piece structure.

Table 1 – Values used in XMAGUN simulations.

Variable	Value
$\mathbf{r_{m1}}$(mm)	3.5
$\mathbf{r_{m2}}$(mm)	7.5
T(mm)	2.95
$\mathbf{r_{f1}}$(mm)	1.6
$\mathbf{r_{f2}}$(mm)	3.05

Variable	Value
$\mathbf{r_3}$(mm)	8.7-6.3
Tp(mm)	1.3
G(mm)	2.25
L/2(mm)	4.25

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Results

Fig. 2(a) presents a view of the permanent magnets, darker color, the pole pieces, light gray, and the mesh used, while Fig. 2(b) the magnetic field profile solution obtained using XMAGUN when $\mathbf{r_3}$= 7.8 mm.

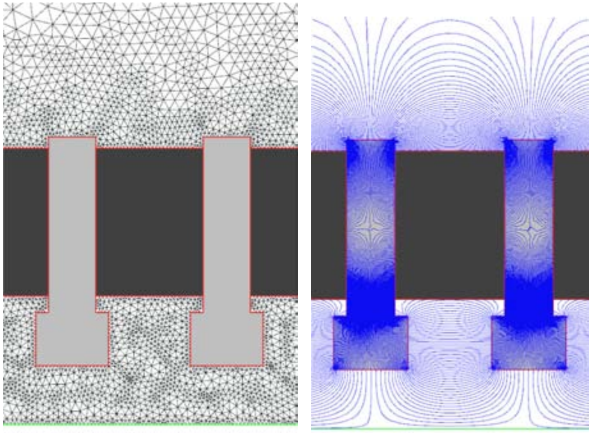
(a) (b)

Figure 2 –Zoom at the PPM mesh structure (a) and the magnetic field profile (b).

Fig. 3 shows the magnetic field peak measured: (a) in the center of the PPM structure using XMAGUN; an infinite PPM structure using (b) ANSYS and (c) analytical [5]. Using five different $\mathbf{r_{ext}=r_3-r_{m2}}$, where $\mathbf{r_{m2}}$ was kept constant while $\mathbf{r_3}$ varied, Fig. 4 shows an absolute growth of the axial peak magnetic field value along the axis when $\mathbf{r_3}$ was reduced.

Conclusion

A FEM formulation to determine the magnetic field in a PPM structure with pole piece was developed. A good agreement was observed, in the measurement of the axial magnetic field peak, between the XMAGUN, at the center of a PPM structure with six pole pieces and five permanent magnets, and the software ANSYS, and the analytical PPM structure modeled as an infinite long PPM structure as well.

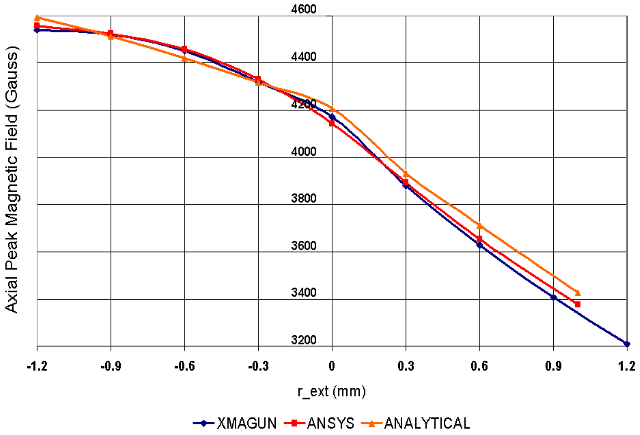

Figure 3 – Variation of the axial peak magnetic field using the XMAGUN, the ANSYS and the Analytical values for distinct $\mathbf{r_{ext}}$.

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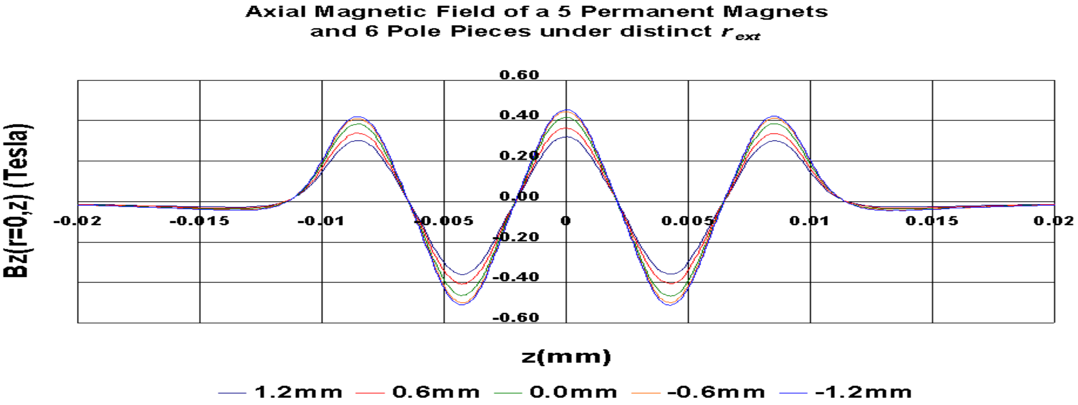

Figure 4 – Axial magnetic field profile along axis for five distinct $\mathbf{r_{ext}=r_3-r_{m2}}$.