NONLINEAR ANALYSIS ON FEM AMPLIFIER WITH CIRCULAR GROOVE GUIDE

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Abstract- FEM amplifier with a novel circular groove guide is proposed and researched both in three-dimensional nonlinear theory and numerical computation in this paper. Efficiency and bandwidth of the FEM are studied including electron beam emittance.

Key words: FEM; circular groove guide; numerical computation; nonlinear theory

1. INTRODUCTION

In recent years, there has been a great deal of interest in free-electron maser (FEM) because of potential applications in industrial, agricultural, military and medical areas. FEM experimental system has been built up in many labs in America, Netherlands, Israel, and other countries [1,2,3,4]. In order to improve the function of the devices, people make strong efforts to develop new transmission guide and many waveguides are suggested to use in FEM. Corrugated rectangular waveguide is adopted in FOM-FEM[5], which is constructed at FOM institute of plasma physics, Netherlands to enhance the interaction between electron beam and wave. While EA-FEL built up at Tel-Aviv university, Israel utilizes two curved parallel plate as a waveguide[6]. In addition, groove guide is paid more attention because of its many advantages such as simple to construct, wider frequency range and high power handling.

Since F.J.Tischer first proposed groove guide in 1952[5], many researchers have analyzed the distribution and characteristics of groove guide [6,7,8]. But most of these grooves which were dealt with are rectangular cross-section or V-shape cross-section. In 1995, Hong-Sheng Yang studied circular groove guide with first-order and second-order approximation[9], and found many interesting features. The circular groove guide is shown in figs.1. As an open waveguide,
with a large cross-section area, it can transmit relatively high radiation power with low losses compared to cylindrical smooth waveguide. In this paper, a FEM amplifier with circular groove guide is studied both in three dimensional nonlinear theory and numerical computation.

The whole paper is organized as following. In section II a universal characteristic equation of $TE_{pm}^{(r)}$ mode is derived, and cutoff wavenumber is analyzed. Three dimensional self-consistent nonlinear equations are derived for FEM amplifier with circular groove guide in section III and numerically studied in section IV. And conclusion is given in section V.

II. CHARACTERISTIC EQUATIONS FOR CIRCULAR GROOVE GUIDE

The structure of circular groove guide shown in fig.1 consists of two parallel conducting plates with spacing $2c$. There is a circular through hole along $Z$ axis at the symmetrical center of the transverse cross section, and the up and down ends are kept open.

It is assumed that the circular groove guide with uniform cross section extends to infinity in the $Z$ direction which is the direction of wave propagation. The guide can be divided into three parts, the central groove region designated by $A$ which has circular boundary with diameter $2a$ and two evanescent side designated by $B$. According to that geometrical shape, we take cylindrical coordinates in region $A$ and rectangular coordinates in region $B$. They have the same $Z$ axis.

There are two types of modes existing in circular groove guide, $TE$ mode and $TM$ mode, and here we discuss $TE$ mode only. The symbols $TE_{pm}^{(r)}$ are used to distinguish different order of modes, where $r$ denotes the number of half waves of electric or magnetic intensity in the $Y$ direction in parallel plate region, and $p$ refers to the number of cyclic variations with $\alpha$ and $n$ represents the nth root of the Bessel function.