INVESTIGATIONS OF ENERGY REGENERATION FEL STRUCTURES OPERATING AT 3 GHZ

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Abstract

The 3D computer simulation code MAFIA has been used to predict the shunt impedance of a 3GHz muffin-tin FEL structure. Different operating wavelengths have been studied and certain limitations on the geometry have been identified. This paper highlights the muffin-tin design philosophy and also the optimum geometry parameterisations that have been completed. An aluminium investigative model has been manufactured and low power perturbation measurements will be performed for comparison with the simulations. A variation with single cells and resonant side-coupling has also been assessed.

1 INTRODUCTION

The introduction of a microwave accelerating structure in the latter stage of an undulator to improve FEL efficiency[1] is not new and has been investigated by a number of laboratories, but principally the concept was developed by Pantell and co-workers. Their initial proposal [2] involved acceleration of the electron beam in a linear accelerator structure created by electro-plating the pole pieces of a planar undulator magnet. However this arrangement did not allow tunability of the undulator gap.

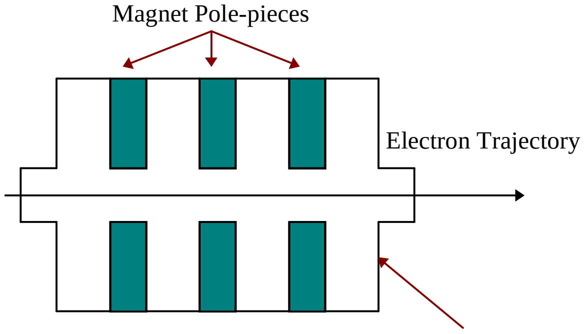

Figure 1: Muffin-tin Accelerating Structure

The muffin-tin FEL combines a linac structure with permanent magnet pole pieces sandwiched between the accelerating cells (see Figure 1). Detaching the accelerating structure from the undulator allows variation of the magnet gap without affecting the accelerating action and thus gives the desired FEL tunability [1]. The accelerating cavities replenish energy lost by the electron beam through the FEL action and lead to at least one order of magnitude increase in power output. Such a planar structure was studied initially at Cornell for a superconducting RF project [3] and more complex millimetre wave variations for acceleration and focusing have been reviewed recently by Henke [4].

Three possible waveguide mode structures have been investigated to determine the most efficient in terms of their fundamental shunt impedance. The modes studied are; 2π/3, π and π/2-mode structures.

2 MAFIA SIMULATIONS

2.1 2π/3-Mode Structure

Initial investigations were to investigate the shunt impedance characteristics of a 2π/3 accelerating structure operating at 3GHz. In order to determine the resonator dimensions various characteristics of the cavity geometry had to be investigated (see Figure 2). The dimensions a, b, d and p were varied until the required operating frequency at a reasonable shunt impedance was obtained. L band solutions were not pursued since the growth of dimension b would prevent an acceptable magnet design.

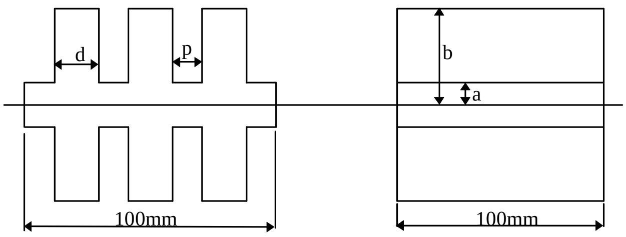

Figure 2: 2π/3-Mode Geometry

The eventual geometry had a beam aperture of a=15mm and an equal mark to space ratio (i.e. cavity to gap ratio or d:p) of 16.66:16.66mm, with an overall half height of b=36mm. This geometry gave an accelerating mode at 3.104GHz with a shunt impedance of 12.7MΩ/m.

The central region close to the axis represents a propagating rectangular waveguide and so the beam aperture would inevitably restrict the 3GHz mode if made too small. At a later stage the resonator width was also increased beyond 100mm in most calculations but this was found not to be a critical dimension.

2.2 π-Mode Structure

With the beam aperture increased to a=20mm, similar investigations were done for a π-mode structure (see Figure 3), again assessing the shunt impedance characteristics and the dimension b that would allow a 3GHz mode to propagate. The solution predicted by

MAFIA was that a 3.126GHz mode could propagate with a shunt impedance of 26.2MΩ/m.

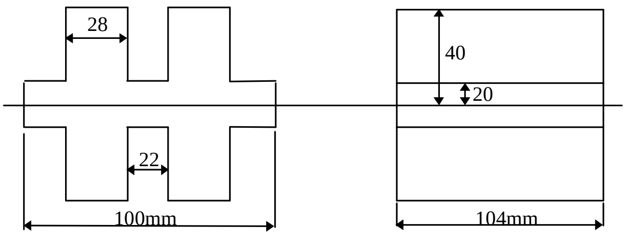

Figure 3: π-Mode Geometry

2.3 *π/2-Mode Structure*

It was then decided to attempt to reduce the operating wavelength of the FEL, by reducing the period of the accelerating structure to π/2 (see Figure 4) and again characterising a 3GHz mode in terms of its shunt impedance. To achieve an optimised propagating 3GHz wave the 20mm side tube extension shown was needed and gave a propagating mode at 2.878GHz with a shunt impedance of 9.4MΩ/m.

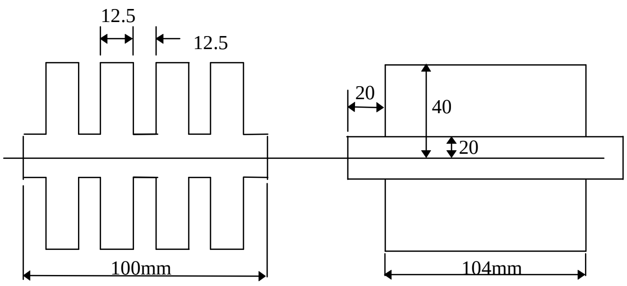

Figure 4: π/2-Mode Geometry

An attempt to reduce the beam aperture significantly below 20mm increased the beam pipe cut-off frequency to beyond 3GHz and therefore the required mode could not propagate. This disappointing result implies that the basic π/2 muffin-tin structure is not useful as the periodic magnet of 50mm period is impractical with the necessary aperture.

3 DEVELOPING THE IDEA - SIDECOUPLING

The MAFIA simulations of basic periodic structures have concluded that without additional coupling mechanisms between the accelerating components the electromagnetic (e-m) field strengths, and hence the maximum shunt impedance achievable, are seriously affected by reducing the undulator gap. In order to overcome the need to preserve on-axis coupling, the π mode structure was chosen as a basis for the initial modelling of the addition of side-coupling, using a coaxial waveguide. The π-mode was selected because it possessed the highest shunt impedance of all variations investigated, plus the fact that the geometry is the simplest for manufacture of a model structure for future experimental comparisons.

MAFIA has been used to investigate a side-coupled multi-cell accelerating structure as shown in Figure 5 below. Modelling this structure arrangement allows each accelerating gap and its associated e-m fields to be isolated from the others. Power is fed from a coaxial waveguide through coupling irises at the side of each accelerating structure. The half gap was now reduced to a=10mm which allows high undulator fields to be achieved whilst preserving good aperture to avoid unwanted radiation diffraction losses.

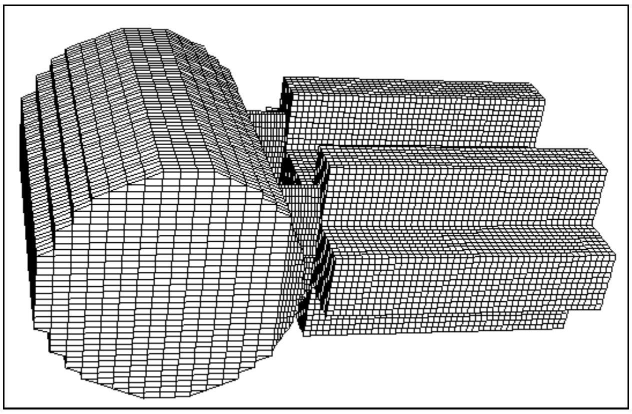

Figure 5: Side-coupled π-Mode Structure

To arrive at a shunt impedance figure, the whole structure was assumed to be resonant (including the waveguide) in the calculation with MAFIA. This enabled e-m field predictions for the accelerating part of the structure (see Figure 6).

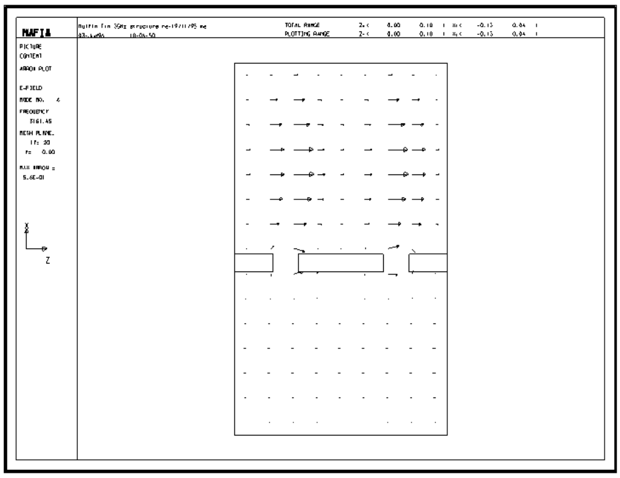

Figure 6: E-field Simulation of π-Mode Structure

It can be seen that the E-field is as expected strong between the accelerating gaps and the reduction in vertical beam aperture still gives a reasonable shunt impedance of 7.3MΩ/m for a fundamental accelerating mode frequency of 3.181GHz.

4 CONCLUSIONS

Planar accelerating structures have been demonstrated to provide a potentially attractive solution for energy recovery FEL schemes. A π-mode structure is well suited to FIR FEL output when an embedded undulator period of 100mm is acceptable. For shorter output wavelengths a side-coupled π/2-mode one shows great promise.

The next step will be to compare the measured performance of a π-mode prototype with these simulations. Following this the side-coupling scheme will be experimentally investigated, initially at π-mode but then for the π/2 version.

REFERENCES

[1] M W Poole et al, ‘Beam Energy Replacement in a Compact FEL’, these Proceedings

[2] A H Ho et al, 'High Efficiency Energy Conversion of Microwave to Optical Power within a Free-Electron Laser Oscillator', IEEE J Quantum Electron QE-23 (1987) 1545

[3] R Sundelin et al, IEEE Trans Nucl Sci NS-20 (1973) 98

[4] H Henke, 'MM-Wave Linac and Wiggler Structures', Proc EPAC-94, London, p 322

[5] ‘MAFIA User Guide’, The Mafia Collaboration, DESY, LANL and KFA, May 1988.