Multi-Mode Cavity Optimization

Benjamin Sims, Michigan State University, Departments of Electrical & Computer Engineering and Physics & Astronomy

John Lewellen, SLAC LCLS-II-HE

Introduction

- Standard accelerating cavities and injectors use a cavity operating at a single TM mode, typically TM 010. Here we explore the effects of multiple modes in the same cavity and how these modes can be mixed to achieve different goals. Our specific goal is to decrease the energy spread of a long bunch using TM 010 and TM 022 modes.

Multi-Mode Cavities

- The interactions between different TM modes changes the field inside the cavity through superposition
- Using a harmonic of the fundamental frequency of the cavity allows for easy implantation of higher frequency modes
- TM0 10 is the standard accelerating mode (Blue)
- TM 022 is a third order harmonic (Orange)
- When combined they create a flatter wave which reduces energy spread (Green)
- Approximates a DC gun with AC fields

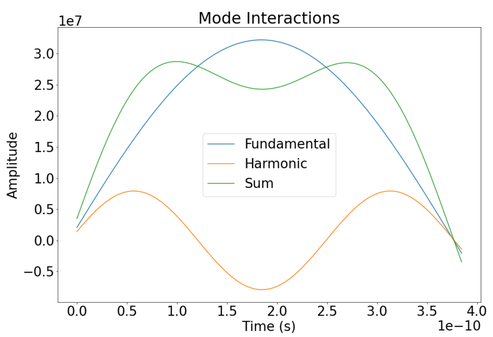


Figure 1: Mode Interactions

Cavity Design

- Designed using Super Fish
- Modes chosen to decrease energy spread
- Beam Pipes included for fringe field effects (5 cm)
- Optimized with simplex method

$$f\left(L_{cav}, R_{cav}, n, m, p\right) := \frac{c}{2\,\pi} \cdot \sqrt{\left(\frac{x_{n,m}}{R_{cav}}\right)^2 + \left(\frac{p \cdot \pi}{L_{cav}}\right)^2}$$

Equation 1: Cavity Frequency

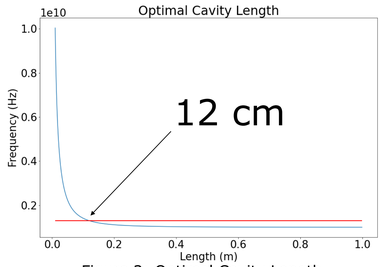
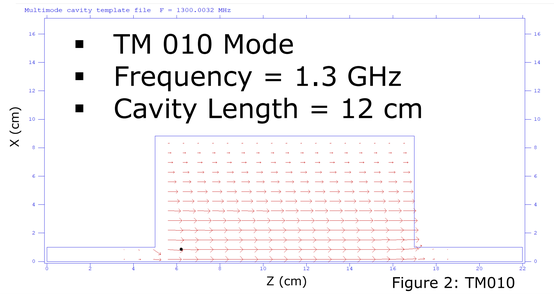
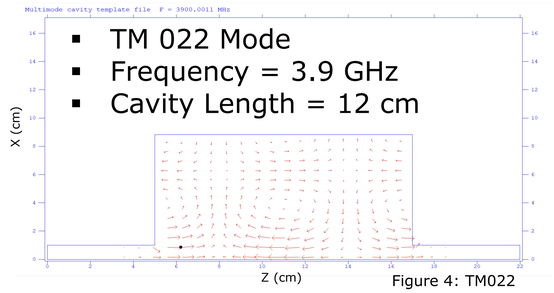


Figure 3: Optimal Cavity Length



- TM 010 Mode
- Frequency = 1.3 GHz
- Cavity Length = 12 cm

Figure 2: TM010



- TM 022 Mode
- Frequency = 3.9 GHz
- Cavity Length = 12 cm

Figure 4: TM022

Simulations

- Simplex Optimizer Parameters
  - Energy Spread

$$Energy\ Spread = \frac{STD\ Energy\ (MeV)}{Average\ Enegry\ (MeV)}$$

Equation 2: Energy Spread

  - Energy Gain
    - 4 MeV Gain Limit (Within 0.001 MeV)
- All Simulations were preformed in General Particle Tracer (GPT)
- Transverse Magnetic Modes
  - TM 010
    - Frequency = 1.3 GHz
  - TM 022
    - Frequency = 3.9 GHz
- Bunch Length = 2.5 cm
- Macro Particles =1,000,000
- Starting Energy = 2 MeV
- No Space Charge Effects

Results

- TM 010 Mode
  - Energy Spread = 9.02e-03
  - Final Bunch Energy = 3.999 MeV
- TM 010 and TM 022 Mode
  - Energy Spread = 2.8e-04
  - Final Bunch Energy = 4.001 MeV

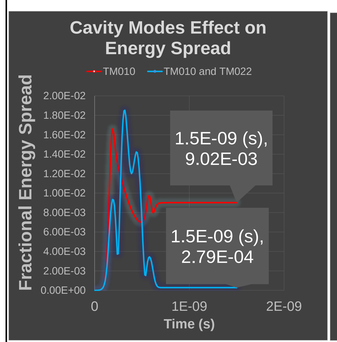


Figure 5: Cavity Modes Effect on Energy Spread

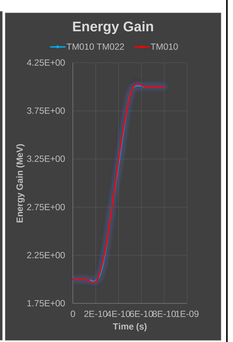


Figure 6: Energy Gain

Discussion

- Different combinations of TM modes can induce different effects on the beam
  - Sharpening the accelerating field to increase energy gain in the cell
  - Cell focusing effects

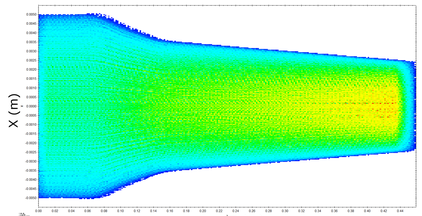


Figure 7: Cell Focusing

- Decreased energy spread contributes to increased coherence over the course of the bunch's life

Conclusion

- The TM 010 and TM 022 mode combination showed the best energy spread reduction
- Further research into different mode combinations for maximizing field gradient are being preformed
  - Possible building and testing of tabletop system in the future

Acknowledgments

- Work supported by the Department of Energy Contract DE-AC02-76SF00515
- Thank you to John Lewellen for his exceptional mentorship, knowledge, and support.