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# INVESTIGATION OF THE BUNCHER EFFECT ON BEAM PROPERTIES IN SW 3-6 MeV LINACS

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*Abstract*

The best quality of an electron beam is the primary goal of a linear accelerator design. Beam-study on a buncher section can lead us to a better perspective of the modulation and acceleration of a beam to optimize the final Gaussian beam. Five setups of different bunchers are designed, optimized, and presented in this article. A more brilliant and converged beam with a higher current, transverse emittance and smaller beam size is the study's goal.

## INTRODUCTION

Standing Wave tubes are one of the most common LINACs in industrial and clinical applications. Capturing the more possible electrons, smaller beam size, and emittance are critical issues in designing these tubes [1].

In this work, an on-axis S-band accelerating tube is considered as a typical tube. The kidney slots adjust the magnetic coupling of the cells. Different setups of the bunchers were designed and simulated for this 30 cm tube. The acceleration of the electrons up to 3 and 6 MeV was studied.

Suggested beta in each buncher is proposed by POISSON SUPERFISH [2]. Designed cavities are tuned and optimized in this 2D code. The tube simulation and beam dynamics study are done in CST SUITE STUDIO [3].

The study can be divided into two main sections:

- Buncher Design & Optimizations.
- Beam Dynamics.

## BUNCHER DESIGN AND OPTIMIZATION

POISSON SUPERFISH is one of the most accurate codes in cavity tuning and optimization procedures [2]. The geometric investigation of the cavities is classified into eight series. First, each model is inserted into SUPERFISH code. Then, they are optimized by concerning the shunt impedance, quality factor, and other figures of merit in the cavity [4].

The geometry of the accelerating cavity is presented in Fig. 1.

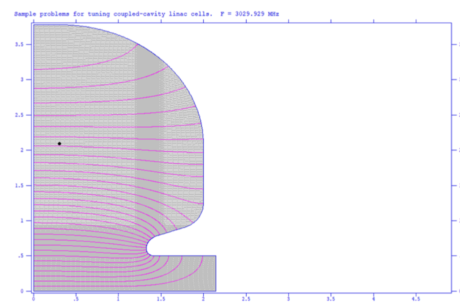

Figure 1: The geometry of the sample cavities in SUPERFISH code.

Geometrical parameters are shown in Table 1.

Table 1: The Geometrical Parameters of the Accelerating Cavities (SUPERFISH & CST)

| Parameters | Dimensions (cm) |
|---|---|
| Diameter | 7.4 |
| Gap Length | 2.65 |
| Outer Corner Radius | 1.69 |
| Inner Corner Radius | 0.35 |
| Outer Nose Radius | 0.2 |
| Inner Nose Radius | 0.1 |
| Bore Radius | 0.5 |

The shunt impedance, quality factor, and other properties of the main cavities are illustrated in Table 2.

Table 2: The Figures of Merit at Different Bore Radius Cavities (SUPERFISH Code) [2])

| Parameters | R2.5-F0.3-G3.1 |
|---|---|
| Frequency (MHz) | 2998 |
| Quality-Factor | 14000 |
| $ZT^2$ $(M\Omega/m)$ | 83.5 |
| Kilp. | 1.8 |
| r/Q | 130 |
| Transient Time Factor | 0.8 |

For the accelerating tube simulation, the SUPERFISH designs are imported in CST Microwave Studio. The Eigenmode solver of the CST can lead us to accelerate fields. The final tube is shown in Fig. 2. In this model, a half cavity is considered as the first buncher.

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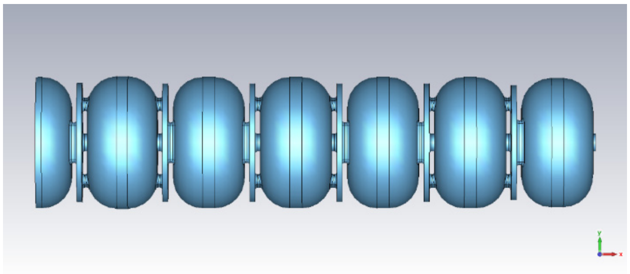

Figure 2: A typical accelerating tube with a half cavity as a buncher.

The prepared accelerating fields can be applied in the PIC solver of the CST. By adjusting the input power, we can simulate the 3 MeV and 6 MeV electron beams.

After finalizing the tube, the buncher cells were designed and adjusted for the 6% coupling between cells at 2998 MHz.

The lengths of the bunchers cells were proposed by BETA.EXE in the SUPERFISH package [2].

The first typical buncher design is including only a half cavity as the buncher. Here, it is presented as (B0.5-0.998-0.998) in our notation.

The next two buncher setups were designed to reach the electrons in 1 MeV. They are presented in the table as the name (B0.5-0.874-0.941) and (B0.5-0.941-0.998). These models are including two and three cells, respectively.

Two other buncher setups were considered to reach the electrons to 2 MeV. They are mentioned as (B0.5-0.944-0.979) and (B0.5-0.979-0.998) to accelerate the cavities by two and three cavities, respectively.

The gap length of each buncher cavity was adjusted in SUPERFISH to remain the accelerating field as much as normal cells. The size of kidney slots also changed to fix the bandwidth of the frequency. As a result, the frequency bands were kept the same in all the cavities.

Then, each buncher cell was optimized again considering the shunt impedance, Kilpatric factor, and quality factor. The final results for each buncher cavity are presented in Table 3.

Table 3: The Shunt Impedance and Kilpatrick-Factor of the Optimized Bunchers

| Geometrical Parameters | Kilp. | Q | $ZT^2$ |
|---|---|---|---|
| B-0.874 | 2.70 | 13360 | 76.81 |
| B-0.941 | 2.68 | 14140 | 78.9 |
| B-0.944 | 2.68 | 14140 | 79.22 |
| B-0.979 | 2.80 | 14072 | 82.38 |
| B-0.998 | 2.84 | 14009 | 83.44 |

## BEAM DYNAMICS

The PIC solver of the CST Particle Studio can help us to simulate the accelerating field.

To calculating the beam dynamics in a PIC solver, a particle source by initial energy of 15 KeV was defined. By defining a PEC plate at the end of this tube, we can analyze the current, beam-emittance, and energy bandwidth on the target. The results are presented in 6 MeV and 3 MeV sections.

### *6 MeV Beam on Target*

The final bandwidth of the energy at 6 MeV electrons is analyzed on the target (Fig. 3).

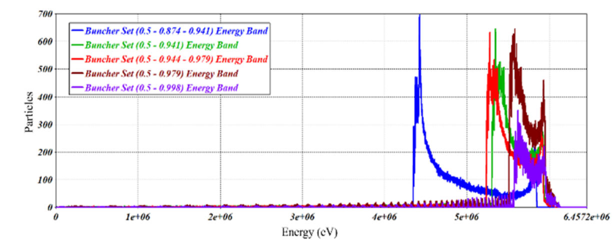


Figure 3: The bandwidth of the energy for the 6 MeV beam.

Based on Fig. 3, the buncher sets designed for 2 MeV show the more narrow-band energy at 6 MeV. On the other hand, the most broad-band energy belongs to the (B0.5-0.874-0.941), trying to reach the electrons to 1 MeV in 3 cavity bunchers.

Final currents and the shape of the bunches are illustrated in Figs. 4 and 5.

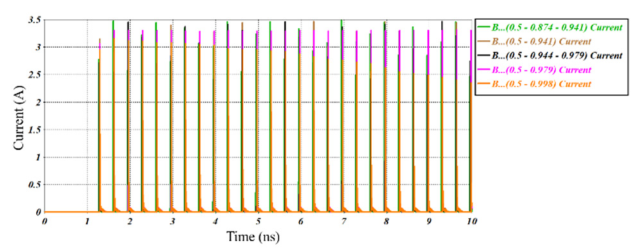


Figure 4: The final 6 MeV current taps on the target.

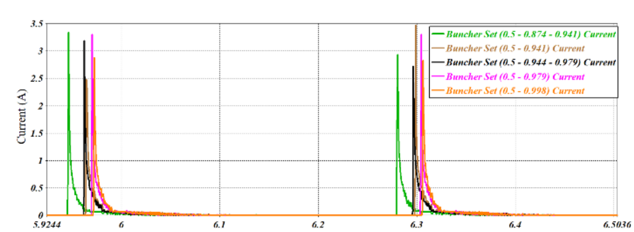


Figure 5: The final 6 MeV bunch comparison on the target.

The final emittance of the beam in the last cavity was evaluated and presented in Table 4.

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Table 4: The 6 MeV Beam Emittance at the Last Cavity

| Geometrical Beta | u-emittance (m) | v-emittance (m) | u/v |
|---|---|---|---|
| B0.5-0.998-0.998 | 1.3e-4 | 1.6e-4 | 0.81 |
| B0.5-0.874-0.941 | 6.8e-5 | 7.6e-5 | 0.89 |
| B0.5-0.941-0.998 | 3.3e-5 | 2.5e-5 | 0.76 |
| B0.5-0.944-0.979 | 2.6e-5 | 3.1e-5 | 0.84 |
| B0.5-0.979-0.998 | 2.9e-5 | 5.8e-5 | 0.5 |

The averaged current and the percentage of the captured electrons in each cavity can be achieved on the target. The results are presented in Table 5 for a 6 MeV beam.

Table 5: The Final Current on the Target for the 6 MeV Beam

| Geometrical Beta | Averaged Current (mA) | Current Percentage |
|---|---|---|
| B0.5-0.998-0.998 | 39.6 | 26% |
| B0.5-0.874-0.941 | 42.0 | 28% |
| B0.5-0.941-0.998 | 41.4 | 28% |
| B0.5-0.944-0.979 | 41.3 | 27.5% |
| B0.5-0.979-0.998 | 40.5 | 27% |

### *3 MeV Beam on Target*

All the simulations were repeated for a 3 MeV beam. The buncher model (B0.5-0.874-0.941) has the highest number of electrons in one energy. This model had the worth results in the 6 MeV section (Fig. 6).

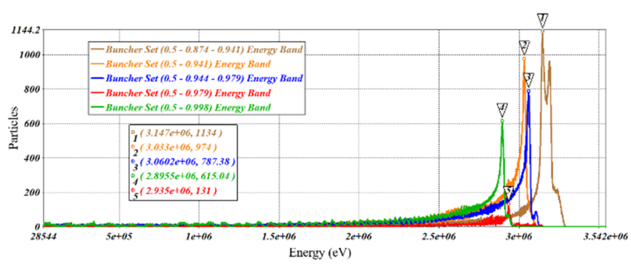


Figure 6: The bandwidth of the energy for the 3 MeV beam.

The final current and bunch shapes are presented in Figs. 7 and 8.

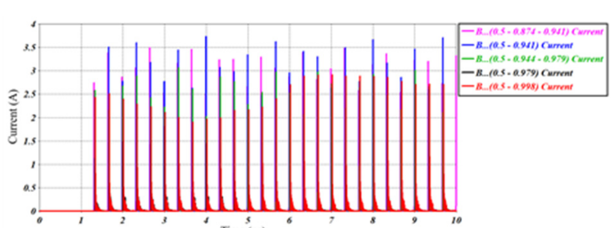


Figure 7: The final 3 MeV current taps on the target.

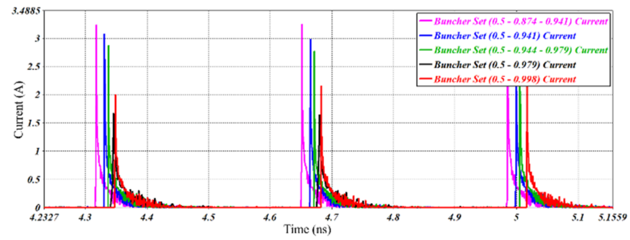


Figure 8: The final 3 MeV bunch comparison on the target.

The beam emittance in transverse directions was presented in Table 6.

Table 6: The 3 MeV Beam Emittance at the Last Cavity

| Geometrical Beta | u-emittance (m) | v-emittance (m) | u/v |
|---|---|---|---|
| B0.5-0.998-0.998 | 8.1e-5 | 7.0e-5 | 0.86 |
| B0.5-0.874-0.941 | 3.7e-5 | 3.8e-5 | 0.97 |
| B0.5-0.941-0.998 | 3.7e-5 | 5.7e-5 | 0.65 |
| B0.5-0.944-0.979 | 5.7e-5 | 9.2e-5 | 0.62 |
| B0.5-0.979-0.998 | 2.6e-5 | 4.3e-5 | 0.60 |

The percentages of the captured electrons are also added to Table 7.

Table 7: The Final Current on the Target for the 3 MeV Beam

| Geometrical Beta | Averaged current (mA) | Current Percentage |
|---|---|---|
| B0.5-0.998-0.998 | 55 | 18% |
| B0.5-0.874-0.941 | 68 | 22.7% |
| B0.5-0.941-0.998 | 63 | 21% |
| B0.5-0.944-0.979 | 58 | 19.3% |
| B0.5-0.979-0.998 | 40 | 13% |

## CONCLUSION

In lower energies, the buncher sets adjusted for 1 MeV energy can cover the most narrow-band energy and higher captured electrons. To reach a 6 MeV energy, both two and three cavity models designed to 2 MeV are suggestable.

In dual electron linacs, both of these energies should be considered. The buncher models that cover two cavities to reach 1 MeV seem proper.

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