

COMPARISON OF DIFFERENT BUNCHER CAVITY DESIGNS FOR THE 4GLS ERLP

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Abstract

A DC photocathode gun is part of the injector of the Energy Recovery Linac Prototype (ERLP) presently being built at Daresbury Laboratory. A buncher is required for the ERLP downstream of the photocathode gun to decrease the relatively long bunches (20-30ps) from the GaAs cathode. Three different single-cell cavity designs were investigated: the Cornell buncher, the ELBE buncher and an EU cavity without Higher Order Mode (HOM) dampers. The properties of these cavities were studied with the computer codes CSTs Microwave Studio and ASTRA. The fundamental frequency and field pattern of each buncher was investigated in Microwave Studio. The EU cavity was scaled from 500MHz to the required frequency for the buncher of 1.3GHz. As the anticipated kinetic energy of the electron beam after the gun is about 350keV a particle tracking code including the space charge forces is mandatory to study the effect of the different buncher cavity designs on the beam dynamics. The particle tracking code ASTRA was used to study the performance of the bunchers for a variety of beam parameters. From these investigations it was found that the three bunchers produce very similar effects on the particle bunch.

INTRODUCTION

Daresbury Laboratory has been given funding for the construction of an Energy Recovery Linac Prototype (ERLP) [1] that operates at a target beam energy of 35MeV and drives an infra-red oscillator FEL. The injector comprises a DC photocathode gun, a buncher cavity and a super-conducting booster. The gun will be operated with a GaAs photocathode. Due to both the intrinsic properties of GaAs and the relatively low operating voltage of 350keV, short electron bunches cannot be produced directly at the gun and typical electron bunch lengths are of the order of 20ps (rms). Further acceleration in the booster operated at near off-crest phase results in strong non-linearities in the longitudinal phase space due to the sinusoidal shape of the RF. This effect can be mitigated by employing a buncher cavity operated at zero-crossing RF phase of the fundamental linac frequency (1.3GHz) for velocity bunching. Three different single-cell cavity designs were investigated.

ELECTROMAGNETIC MODELLING

Three single-cell cavity designs were investigated: the Cornell buncher, the ELBE buncher and an EU cavity. The buncher options were modelled using Microwave Studio. The EU cavity [2] was scaled from 500MHz using the parameter sweep eigenmode solver. For the

cavity to be resonant at 1.3GHz it was scaled to 38.4% of its original size. The Higher Order Mode (HOM) dampers were excluded in this model. No additional work was required for the modelling of the Cornell [3] and ELBE cavities. The cavities were analysed using the eigenmode solver to produce a field map which could be used in ASTRA, along with other important properties of the cavity. The electric field for the fundamental frequency for all three cavity designs is shown in Figure 1; arrows indicate the maximum field points and directions. The colour of the arrows show maxima, red, and minima, green, relative to each design and therefore cannot be compared between the designs.

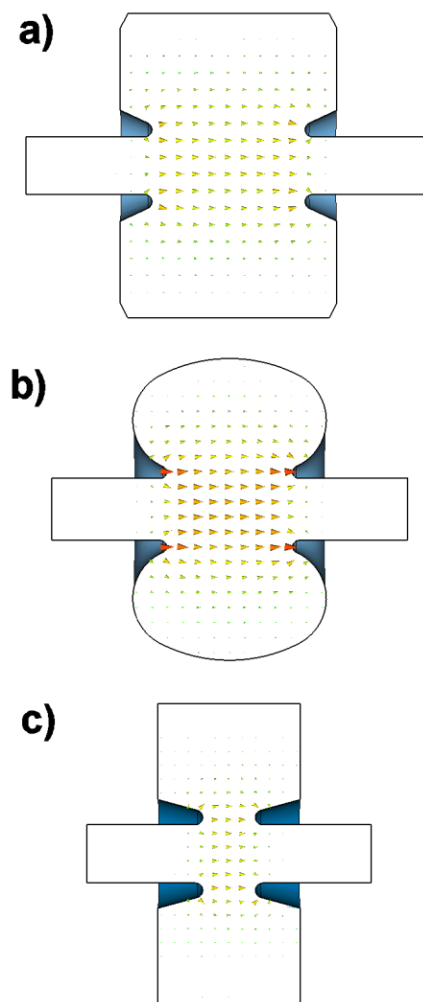


Figure 1: Cavity field plots for the fundamental frequency for a) the EU cavity, b) the Cornell cavity and c) the ELBE cavity (for further explanation see text).

The dimensions of these cavities are given in Table 1 as the images in Figure 1 are not to scale. It can be seen

from this that the ELBE cavity is much smaller than the other two, which are similar in size and differ mainly in their shape.

Table 1: Dimensions of the buncher cavities

	EU cavity	Cornell	ELBE
Radius	81.5	85	67.5
Max Width	115.8	109.1	62
Min Width	54.87	70.9	20

The on-axis electric field for each of these cavities is compared in Figure 2.

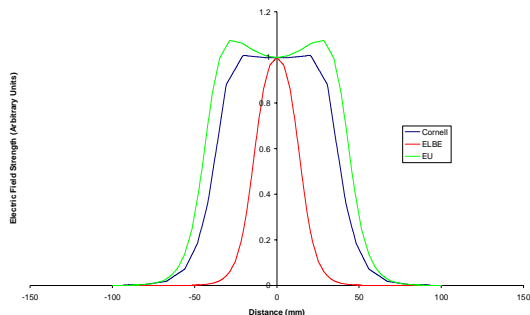


Figure 2: Buncher E-field on axis

The values of R , R/Q and peak voltage were also investigated and are given in Table 2. A field of 1MV/m is required across the cavity. Taking the values for the shunt impedance and quality factor from the eigenmode solver in the models and the 1MV/m requirement the following variables, in Table 2, were calculated. For a true comparison the voltage and power of the ELBE cavity must be scaled by 1.75 so as to obtain the same acceleration with its smaller accelerating gap.

Table 2: Buncher Parameters

	EU cavity	Cornell	ELBE	ELBE×1.75
R (Ω)	7.73E+05	7.30E+05	1.16E+06	1.16E+06
Q	2.10E+04	2.20E+04	1.41E+04	1.41E+04
R/Q (Ω)	36.81	33.18	82.13	82.13
Voltage (kV)	54.87	70.90	20.00	35.00
Power (W)	1947.42	3443.02	173.01	529.84

The EU and Cornell cavities have similar values for resistance and quality factor but have different peak voltages due to the different sizes of the gap. The ELBE cavity differs in all these values due to its size. This makes a dramatic difference to its power requirements.

ASTRA MODELLING

At the foreseen injector operation with a beam energy of 350keV and bunch charge of 80pC the effect of space charge forces on the beam dynamics cannot be neglected.

Hence, the ERLP injector can only be modelled properly with multi-particle tracking codes that include space charge effects. The multi-particle tracking code ASTRA [4] was used to study the effect of the three different buncher designs on the beam dynamics. The on-axis electric field distributions generated by Microwave Studio were used as input files for ASTRA.

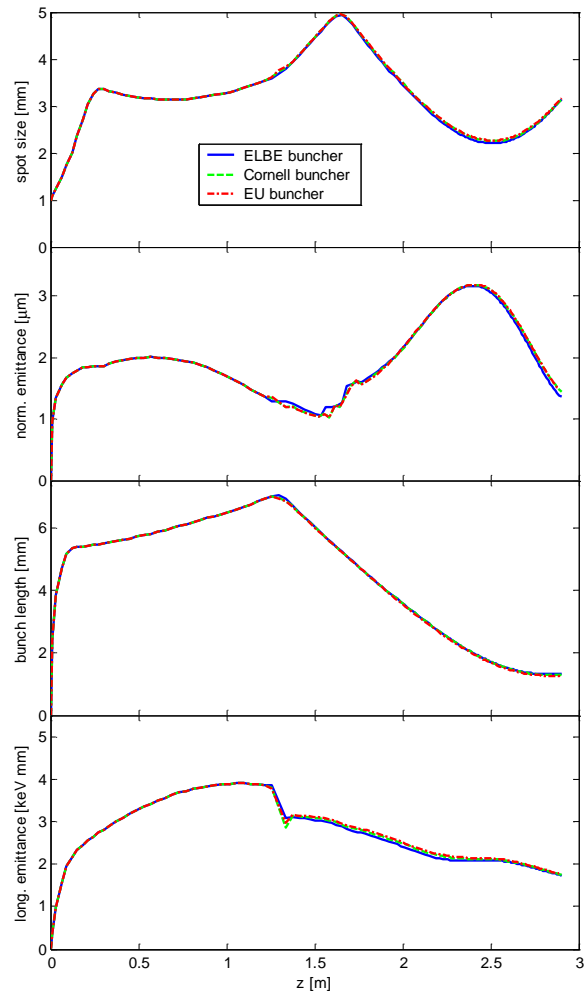


Figure 3: Evolution of rms values of the beam size, transverse emittance, bunch length and longitudinal emittance for the different bunchers.

The evolution of the rms spot size, bunch length and transverse/longitudinal emittance for the three bunchers is compared in Figure 3. The beam dynamics has been modelled from gun through a solenoid ($z = 0.23\text{m}$), the bunchers ($z = 1.3\text{m}$) and another solenoid ($z = 1.65\text{m}$). The bunchers were operated at zero-crossing RF phase. Since the ELBE cavity is shorter than the Cornell and EU cavities the field gradient of the ELBE cavity was scaled by a factor of 1.75.

Figure 4 depicts the longitudinal phase space at the buncher position and the rotated phase space ellipse 1.1m

downstream for all three bunchers. As can be seen from Figures 3 and 4, all bunchers show a similar behaviour regarding the beam dynamics. This study did not consider either Higher Order Modes (HOMs) or Beam Break-Up (BBU) instabilities.

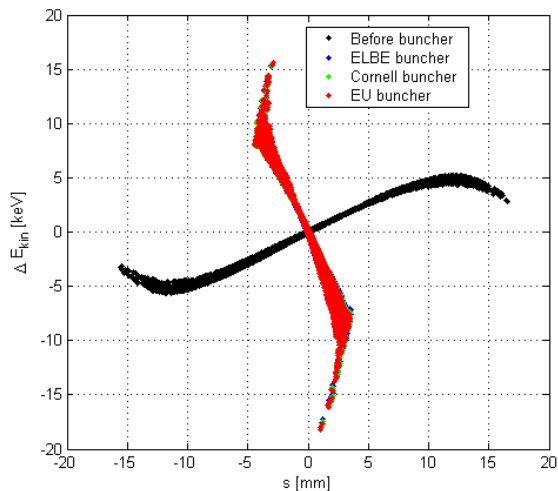


Figure 4: Longitudinal phase space upstream (black) and 1.1m downstream the bunchers.

FURTHER ELECTROMAGNETIC MODELLING

The ELBE buncher was studied further. Two tuning stubs were added to the ELBE model, modelled as two small posts of a perfectly electrically conducting material. These were inserted to their maximum position of 11mm inside the cavity. The cavity had a resonant frequency of 1.2977GHz. When the prongs are at their maximum extension the resonant frequency is 1.3014GHz. This gives a tuning range of 3.7MHz.

COMPARISON OF THE ELBE DATA TO MODELLED RESULTS

The ELBE buncher has been in service for more than a year at the radiation source ELBE [5], Forschungszentrum Rossendorf. Superfish data of this cavity has been compared to the data from Microwave Studio: there is good agreement between the two sets of data which may be further improved by a denser mesh in the Microwave Studio model. This comparison is shown in Figure 5.

The ELBE cavity can be seen in the centre of the photograph shown in Figure 6. It is made of copper and is water cooled. The beam is travelling from right to left, and in the left hand side of the image the next solenoid can be seen.

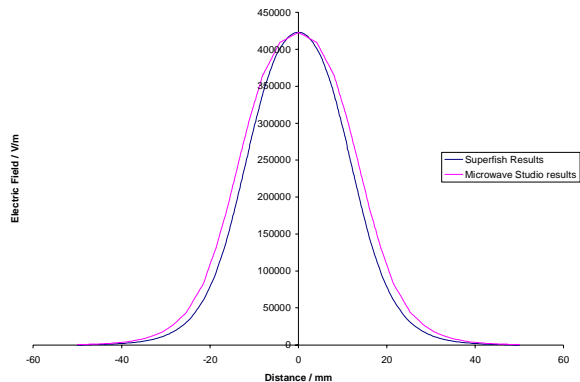


Figure 5: Comparison of model against the ELBE Superfish data.

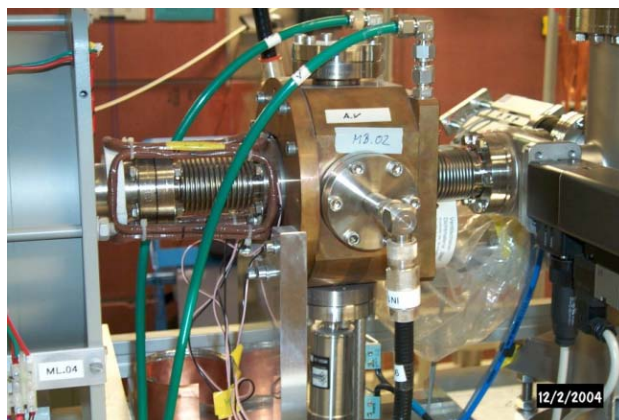


Figure 6: ELBE cavity installed at the ELBE facility.

CONCLUSION

The modelling of the three different buncher cavities produced very similar results and all three bunchers were considered for the ERLP. Due to the similarity in the modelling results the ELBE buncher was chosen for other reasons: it requires the least RF power of the three designs (cf. Table 2), it has already been successfully operated at the ELBE facility (Figure 6) and it is considered the easiest to manufacture.

REFERENCES

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