TRAVELLING WAVE ACCELERATING STRUCTURE FOR AREAL 50 MeV ENERGY UPGRADE

A. S. Vardanyan*, V. A. Danielyan, V. S. Dekhtiarov, B. A. Grigoryan, L. S. Hakobyan, T. M. Markosyan, A. S. Simonyan, CANDLE Synchrotron Research Institute, Yerevan, Armenia
W. Ackermann, TU Darmstadt / TEMF, Darmstadt, Germany
A. V. Tsakanian, Helmholtz-Zentrum Berlin fuer Materialien und Energie, Berlin, Germany

Abstract

AREAL facility development implies energy upgrade to 50 MeV in order to drive a THz free electron laser. To reach this goal, the installation of two 1.6 m long S-Band travelling wave accelerating sections, with nominal accelerating gradient of 15 MV/m, are foreseen. In this paper the design study of accelerating sections along with the matching performance of RF couplers are presented. The simulations are performed using the CST Microwave Studio.The first results of the accelerating structure prototype fabrication are discussed.

INTRODUCTION

Advanced Research Electron Accelerator Laboratory (AREAL) is a 50 MeV electron linear accelerator project with a laser driven RF gun being constructed at CANDLE Synchrotron Research Institute [1]. In addition to its applications in life and materials sciences, the project aims as a test facility for advanced accelerator and radiation source concepts.

The first stage of project implementation, the laser driven RF gun is completed, which provides electron energy of 5 MeV, nominal bunch charge of 200 pC and normalized emittance of 1 mm-mrad [2]. The RF gun is an S-band 1.5-cell standing wave cavity designed for REGAE facility at DESY [3] with a shunt impedance of 2.12 MΩ, an unloaded quality factor of ~15000and a filling time of about 0.7 µsec. The RF gun operates with 7 MW power klystron (pulse duration $\sim 4\mu s$). The cavity maximum voltage is about 5 MV, which corresponds to accelerating electric field amplitude of 117 MV/m.

AREAL energy upgrade implies the usage of two 1.6 m long S-Band travelling wave structures with maximum acceleration gradient of 15 MV/m. The estimated RF power, required for energy gain up to 50 MeV, is about 40 MW.

The CST microwave studio [4] is used for the design and simulation of the accelerating structures along with input and output couplers. The first 5-cell accelerating structure prototype has been produced and tested.

DESIGN AND CST SIMULATIONS

For AREAL accelerating sections, a conventional constant impedance travelling wave structure has been chosen due to its simplicity, easy production and tuning.

Following the well-known theory of TW disc loaded structures [5], the energy gain in the constant impedance structure is only 1% less as compared to the constant gradient one, assuming the same shunt impedance. For both structures the accelerating voltage V is given by $V = A\sqrt{R_{sh}P}$, where P is the input power, R_{sh} is the shut impedance, A is the voltage coefficient conditioned by the accelerating section attenuation constant τ (Fig.1).

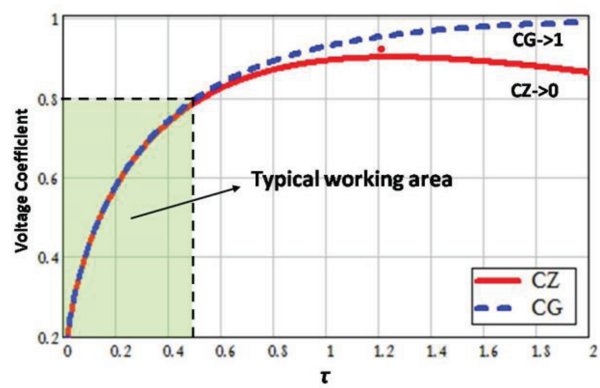

Figure 1:Voltage coefficient for constant gradient (CG) and constant impedance (CZ) accelerating structures.

The general requirements to AREAL accelerating structures are listed in Table 1.

Table 1: Accelerating Structure Parameters

Frequency	2.9979 GHz
Phase advance	2π/3
Accelerating gradient	>15 MeV/m
Length	< 1.7 m
Filling time	< 1us

The complete EM design of the cavity was done using CST Microwave Studio [4].

Periodic Cell Design

The periodic cell length is taken $\lambda_{RF}/3$~33.325 mm which is defined by the $2\pi/3$ phase advance per cell of travelling wave. Cells are separated by a 5 mm thickness wall, the iris radius is $Rg = 5mm$. In addition, the one-side blending with $bR0 = 10mm$ radius is introduced in the cell pillbox part (Fig. 2), to increase the shunt impedance and to reduce the losses.

* vardanyan@asls.candle.am

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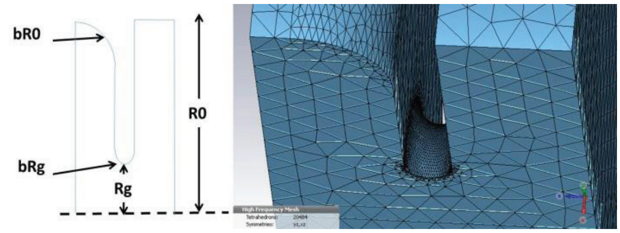

Figure 2: Periodic cell geometry and the mesh.

In all simulations tetrahedral mesh with5° curving radius was used to accurately resolve the small blended parts of the geometry.

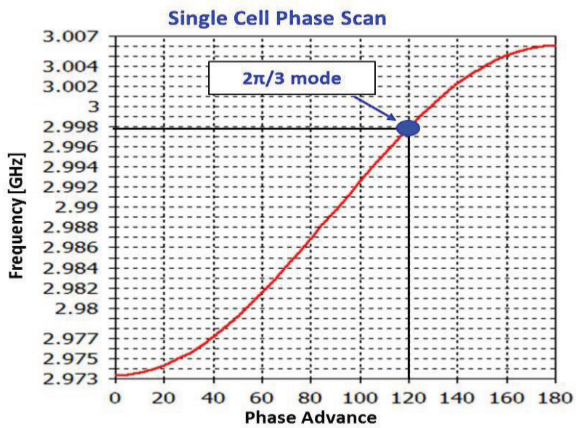

Figure 3: Dispersion diagram.

In Fig. 3 the phase scan (dispersion diagram) for the periodic accelerating structure is presented. For the 2.9979GHz travelling wave with 2π/3 phase advance the dispersion slope gives the group velocity of $v_g/c \approx 0.989\%$ (c-velocity of light). The corresponding quality factor is $Q \approx 14100$, which results in $\alpha_0 \approx 0.225\, m^{-1}$ attenuation constant per unit length.

Coupler Optimization

The coupler geometry and mesh are presented in Fig. 4. The coupler cell length is 28.3 mm and the corresponding rectangular feeding waveguide (WG) dimension is 72x28.3 mm. The numerical simulations show that for the given iris radius the coupler WG-cylinder transition hall openingis a sensitive parameter for the right TW cavity mode coupling. The optimum transition hall opening is chosen $d = 25mm$.

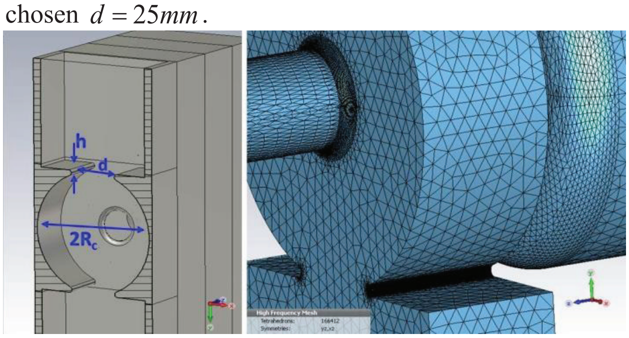

Figure 4: Coupler geometry and mesh.

As a starting point for coupler design the optimisation by symmetric geometry is used, which corresponds to the dual feeding coupler solution. The reduced model, consisting of two couplers and two periodic cells, is shown in Fig. 5.

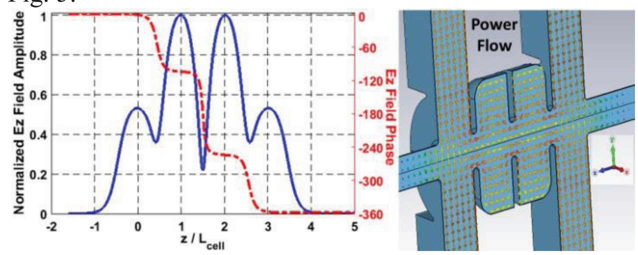

Figure 5: Coupler dimension optimization.

The tuned couplers with $R_c = 37.833mm$ ensure2π/3 phase advance per cell. The accelerating field amplitude, being always positive, indicates the travelling wave.

The two parallel plates are added to one coupler WG side, which act as RF reflector for 3 GHz frequency. Th corresponding back port can be used for vacuum pumping. The design frequency was achieved by tuning the position of reflector plates ~134 mm away from cavity axis. The accelerating field performance and S parameters are presented in Fig. 6.

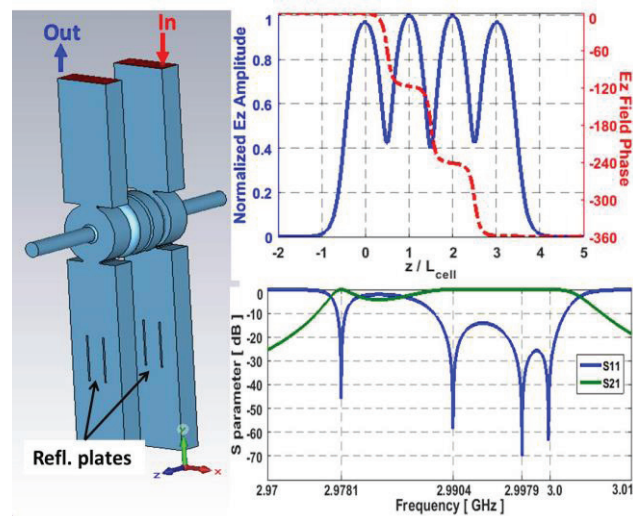

Figure 6: Reduced cavity model: TW accelerating field and S parameters.

46 Cell Accelerating TW Cavity

Finally, the complete accelerating cavity is obtained by adding 42 periodic cells to already tuned reduced-model. The resulting RF parameters, like S11 and accelerating field amplitude, are presented in Fig. 7.

In the final simulations copper was taken as a background material to extract the realistic gradients and actual propagated (lossy) RF power distribution along the cavity (Fig. 8). The complete cavity has effective length of ~1.5 m and filling time of about 0.61 μs. The accelerating total voltage is related to the input power as:

$$V[MV] \cong 4.942 \cdot \sqrt{P[MW]},\ P_{out}/P_{in} \cong 0.497$$

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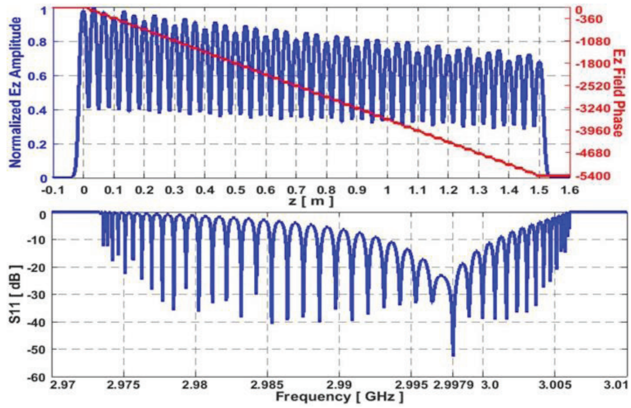

Figure 7: TW cavity accelerating field and S11 parameter.

It is worth mentioning that, due to the small iris radius, about 50% of the input RF power is dissipated in the cavity. For the 40 MW input power an energy gain of about 30 MeV per accelerating section is foreseen.

COOLING AND PROTOTYPING

Structure Cooling

Since the power loss along the accelerating structure (Fig.8) is nearly linear (red line), for the given average input power the required constant temperature along the entire structure can be obtained by providing the appropriate water flow rate.

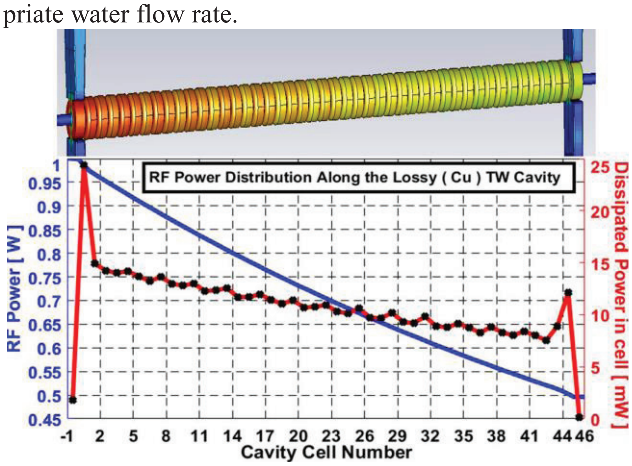

Figure 8: Propagated and dissipated power distributions along the lossy TW cavity.

The performed simulations for mean 300 W input power show (Fig. 9), that for the water flow of 20 l/min, the temperature deviation along the structure will not exceed 0.5°C at the 40°C temperature level.

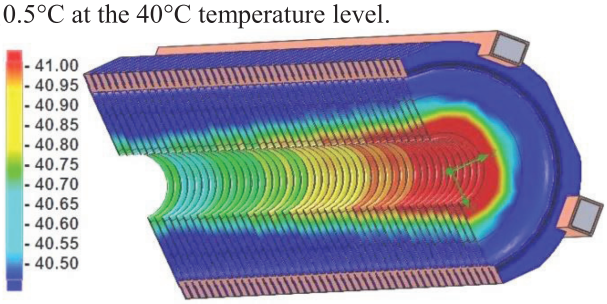

Figure 9: Temperature gradient along TW structure.

Copper thermal conductivity and outer surface heat loss are taken into account. Additional cooling loops are foreseen for input/output couplers.

Prototyping and Quality Control

Following the design specifications a 5-cell prototype structure has been constructed and tested at the mechanical workshop of CANDLE Institute (Fig. 10). To obtain structure high performance, the final machining of cups has been proceeded with the CNC milling machine. For the structure fabrication and tests, special devices and tools were designed, fabricated and used [6].

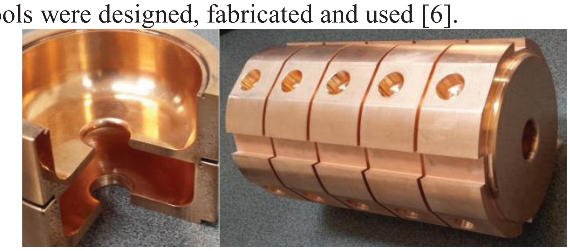

Figure 10: Brazing test with 2-cell (left) and5-cell prototypes (right).

The mechanical measurement results are listed in Table 2.

Table 2: Mechanical Measurement Results

	Design tolerance μm	Measured tolerance μm	Reproducibility μm
Cup diameter	-20	-10	
Height	-15	-6	± 2÷3
Iris radius	-10	-4	
Surface roughness	0.005		

CONCLUSION

The S-Band travelling wave structure for AREAL energy upgrade is designed. The optimal coupler performance is developed. The structure cooling approach is studied. The mechanical measurements of the first 5-cell prototype structure are performed.

Based on the design and first test results, the production of the whole accelerating section is in process.

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