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AN OPEN RADIOFREQUENCY ACCELERATING STRUCTURE

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Abstract

We report an open multi-cell accelerating structure. Being integrated with a set of open-end waveguides, this structure can suppress high-order modes (HOMs). All the accelerating cells are connected at the side to rectangular cross-section waveguides which strongly coupled with free space or absorbers. Due to the anti-phased contribution of the cell pairs, the operating mode does not leak out, and has as high-quality factor as for a closed accelerating structure. However, the compensation does not occur for spurious high-order modes. This operating principle also allows for strong coupling between the cells of the structure, which is why high homogeneity of the accelerating fields can be provided along the structure. We discuss the obtained simulation results and possible applications. Its include a normal conducting high-shunt impedance accelerator, a tunable photoinjector's RF gun, and a high-current, high-selective SRF accelerators.

INTRODUCTION

Progress of modern particle accelerators is associated with high intensity beams. An open accelerating structure that keeps all advantages of classical closed structures is a dream of all investigators dealing with high-current beams. We will show that the open structure can bring lots of other benefits.

In this paper we consider a π-mode standing wave accelerating structure only. The idea is to couple neighbour cells by means of a waveguide keeping symmetry. Because fields in the considered neighbour cells have opposite directions these cells cannot radiate power in the single mode waveguide, but near-field coupling is non-zero. Therefore, if the mentioned waveguide is long enough it can be open, this does not perturb any RF properties of the structure. Let us consider three examples.

HIGH SHUNT IMPEDANCE ACCELERATING STRUCTURE

Let us consider a 9.3 GHz normal conducting accelerating structure (Fig. 1). It consists of a chain of the cells so that each cell has two coupling holes. Each hole sees a single-mode waveguide that is to be open. For simulations we used absorbers shown in pink in Fig. 1 at far waveguide end ($\varepsilon'=\mu'=1$m $\tan\delta_\varepsilon=\tan\delta_\mu=1$). The E- and H- field structures of the operating mode for coupling hole size 8 mm in transverse to structure's axis direction are shown in Figs. 2 and 3, respectively. One can see that E-field distribution differs from the classical mode distribution in a closed cell only at coupling hole's area. There are no significant E or H field enhancement. That is why, this structure made of copper at room temperature has high shunt impedance that exceeds 200 MΩ/m (Fig. 4). From this point of view, this open structure is similar to other side coupled structures, traveling wave [1] or standing wave [2]. In our case the side surface that is responsible for coupling and seen by RF power has the smallest area. This fact explains the mentioned high shunt impedance. Note that the larger coupling hole (stronger coupling) the less the shunt impedance.

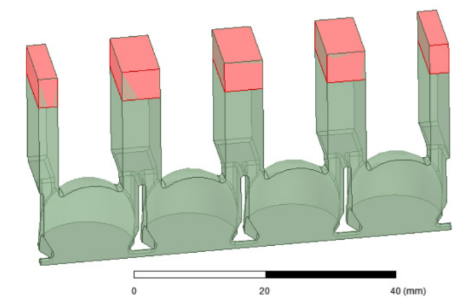

Figure 1: 9.3 GHz π-mode standing wave structure.

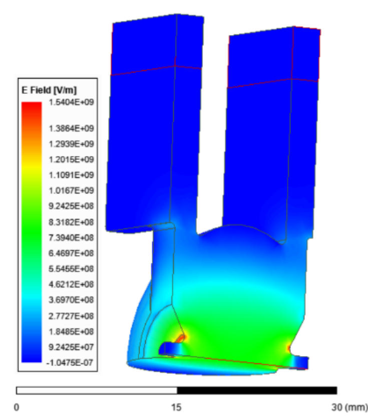

Figure 2: E-field distribution for the operating mode.

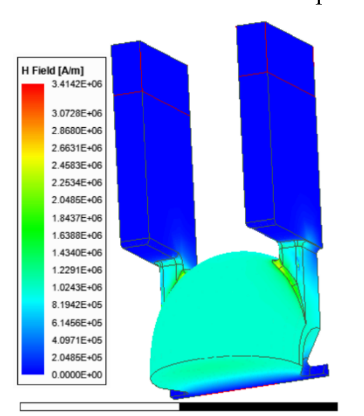

Figure 3: H-field distribution of the operating mode.

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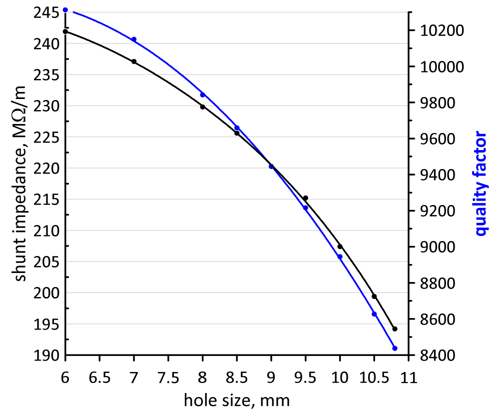

Figure 4: Shunt impedance and Q-factor vs coupling hole size.

Figure 5 shows the "dispersion" curve for the operating mode for coupling hole size 8 mm. For an open structure each frequency is a complex number. In our case the operating mode has maximum of Q-factor at phase equal to π. If the phase advance increases or decreases the Q-factor drops very fast.

Note that open waveguides can be used to provide distributed individual feeding for each cell that might be important at high gradients. In addition, these waveguides can provide fast and efficient pumping.

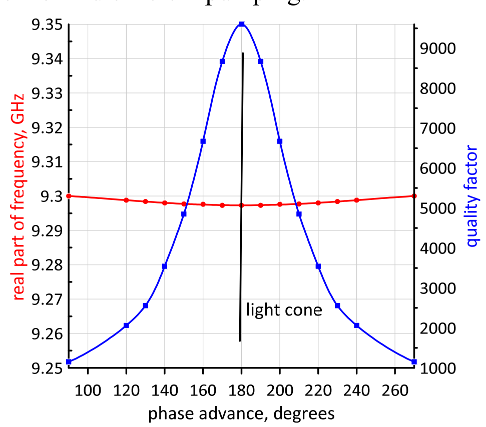

Figure 5: Real part of frequency and Q-factor vs phase advance per cell.

PHOTOINJECTOR RF GUN

In this example let us consider a 11.7 GHz normal conducting RF gun at π-mode consisted of 2,5 cells (Fig. 6). Each cell has rectangular cross-section. By selecting x- and y-sizes of cells one can obtain fully symmetric field distribution (Fig. 7).

For X-band it is important to constitute RF gun of several cells in order to have a high energy gain and low emittance [3]. In a multi-cell gun one of key requirements is to obtain good field balance for the operating mode and to avoid excitation of other spurious modes with other than operating mode longitudinal field structures. Both problems are solved for the open RF gun. We set the strongest coupling between cells (the largest coupling holes). This guarantees the field balance. On the other hand, the large holes supress spurious modes especially if we look for spurious modes with other than operating mode longitudinal structures (see Fig. 5).

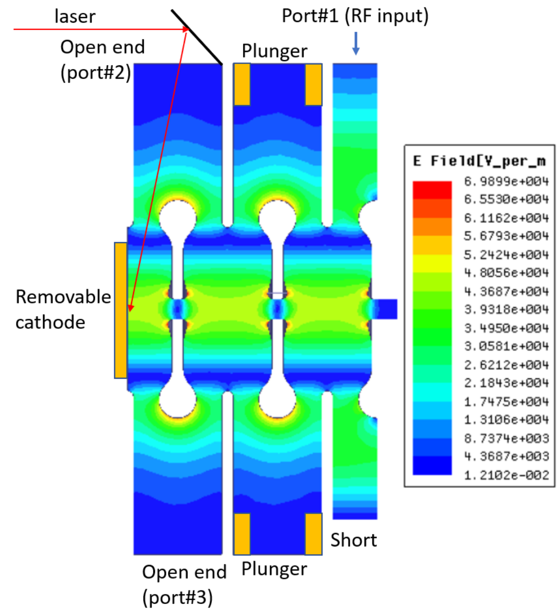

Figure 6: 11.7 GHz 2,5 cell standing wave RF gun.

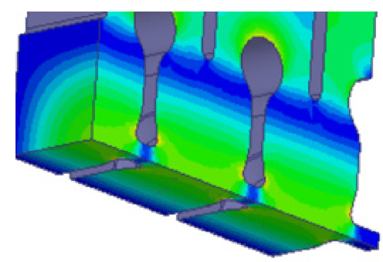

Figure 7: Zoom of E-field distribution.

The considered RF gun (Q~200) was designed to be fed with as short as 9 ns 300 MW pulses. It had the built-in RF coupler that used a short in one of two end waveguides. Figure 8 shows S-parameters of the gun. The S_{11} is represented by red curve, the S_{12} and S_{13} coincide (blue curve). One can see that the gun is strongly overcoupled, there is no power leakage through the side ports.

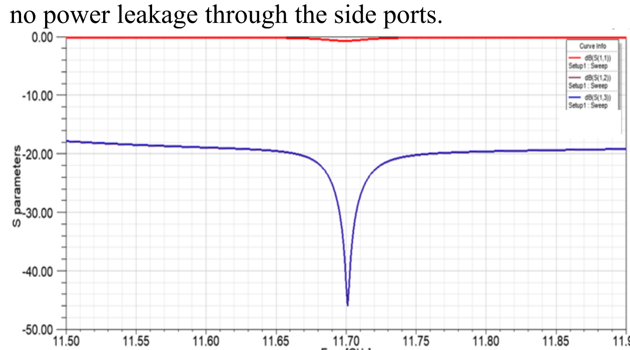

Figure 8: S-parameters for gun's resonator.

Note that the proposed RF gun can provide easy access of laser to the cathode. The cathode could be removable one if to use a so-called brazeless engineering design [4]. Among additional benefits for the open design let us notice

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an opportunity to organize fine tuning by means of movable plungers and easy pumping through the side waveguides.

HIGH SELECTIVE SRF ACCELERATING STRUCTURE

SRF accelerating structures driven with high-current beams require to absorb High-Order Modes (HOMs) efficiently. Our open accelerating structure could be helpful for this case too.

Let us consider a 1.3 GHz accelerating structure shown in Fig. 9. This structure consists of four cells only. It has couplers with choke reflectors. The E-field structure is represented in Fig. 10. In order to supress strongly spurious modes we again used the design with large coupling holes like it was described in the previous section. These large holes must provide excellent field balance for the operating mode. We assume that waveguide ends would be filled with ceramic absorbers in real engineering design.

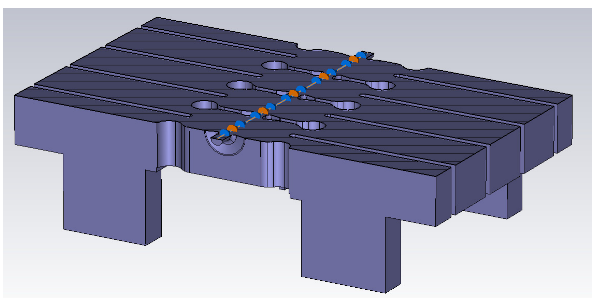

Figure 9: 1.3 GHz open SRF accelerating structure.

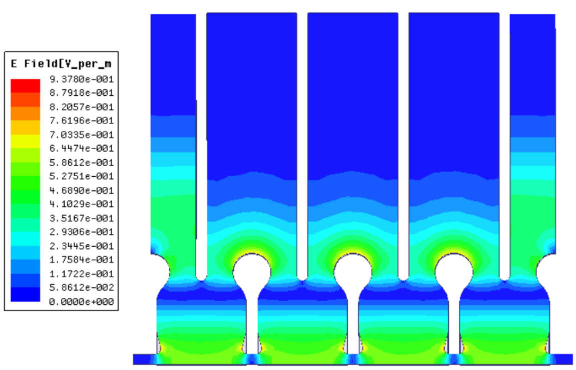

Figure 10: 1.3 GHz operating π-mode (Q=10^8).

In order to explore selective properties of the structure, we simulated moving point charge along structure's axis with CST code. Then we recorded as long as 100 ns wakefield in the middle of the structure and analysed Fourier spectrum of this wake. The result is shown in the Fig. 11. One can see that the biggest peak at 1.3 GHz corresponds to the operating π-mode that had as high as 10^8 Q-factor. There are several small peaks. In particular, one peak seats at 0.9 GHz, another one is seen at 1.8 GHz. Field structures of these spurious modes are plotted in Figs. 12 and 13, correspondingly. Remarkably, both modes had almost four orders less Q-factors in comparison with the Q-factor of the operating mode.

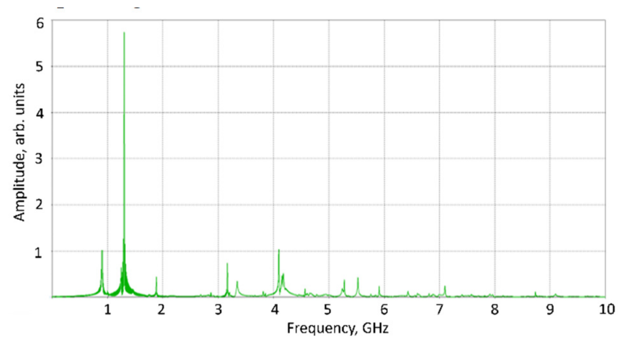

Figure 11: Spectrum excited by point charge.

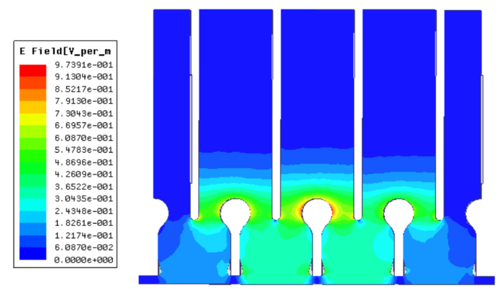

Figure 12: 0.9 GHz spurious mode.

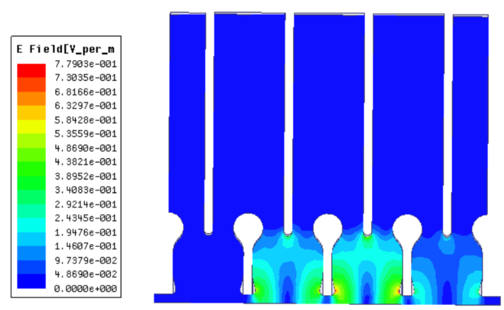

Figure 13: 1.8 GHz spurious mode.

CONCLUSION

An open accelerating structure can become a good base for a normal conducting high-shunt impedance accelerator, a tunable photoinjector's RF gun, and a high-current, high-selective SRF accelerators.

REFERENCES

[1] V. A. Dolgashev, "Traveling Wave Linear Accelerator With RF Power Flow Outside of Accelerating Cavities", in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 48-51. doi:10.18429/JACoW-LINAC2016-MOOP04

[2] S. Tantawi *et al.*, "Design and demonstration of a distributed-coupling linear accelerator structure", *Phys. Rev. Accel. Beams*, vol. 23, p. 092001, 2020. doi:10.1103/PhysRevAccelBeams.23.092001

[3] S. V. Kuzikov *et al.*, "An X-Band Ultra-High Gradient Photoinjector", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp.2986-2989. doi:10.18429/JACoW-IPAC2021-WEPAB163

[4] S. V. Kuzikov, S. P. Antipov, and P. V. Avrakhov, "Compact 1 MeV Electron Accelerator", in *Proc. NAPAC'19*, Lansing, MI, USA, Sep. 2019, pp. 942-944. doi:10.18429/JACoW-NAPAC2019-THYBB3