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HIGH-GRADIENT SHORT PULSE ACCELERATING STRUCTURES

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Abstract

High gradients are necessary for many applications of electron accelerators. Since the maximum gradient is limited by effects of RF breakdown, we present the development of an electron accelerating structure operating with a short multi-megawatt RF pulse. The structure exploits the idea to decrease the breakdown probability due to RF pulse length reduction. This concept requires distributing RF power so that all accelerating cells are fed independently of each other. This implies the waveguide net system, which allows delay and to properly distribute RF radiation along the structure, to keep synchronism of particles and waves. We have designed an X-band pi-mode structure including the RF design, optimization, and engineering. The structure will be tested as an RF power extractor at the Argonne Wakefield Accelerator Facility for two-beam acceleration experiments. In this regime we anticipate obtaining 10 ns, gigawatt power level RF pulses generated by a train consisting of eight 25-50 nC relativistic bunches.

INTRODUCTION

Accelerating gradient is a key parameter for many acceleration applications [1]. In X-band, the best results have been achieved at SLAC and CERN, which provide 100-120 MV/m pulses of 200 ns duration [2]. RF breakdown and pulse heating are the greatest obstacles to increasing gradient. Numerous experiments carried out have shown that the RF breakdown threshold depends on structure exposure time [2]. Also, the pulse heating temperature decreases with shorter pulse length [3]. In this paper, we propose to reduce the pulse duration to ~1 ns scale. This proposed short pulse operation requires new accelerating structures. Such structures must be broad band, possessing low loaded Q-factors to accommodate short pulses. These structures become comparable to THz single cycle structures developed in several labs [4-5]. For low-Q structures, a high shunt impedance could be reached using a side-coupling design. On the other hand, short pulse structure design can be simplified. This is because possible reflection does not spoil operation, if the distance between the RF source and the acceleration structure is larger than the pulse duration. There are appropriate high-power (~1 GW) X-band RF sources based on relativistic electron beams [6] for such short pulse accelerating structures.

A SHORT PULSE ACCELERATING STRUCTURE WITH SIDE-COUPLING

A side-coupled design is the natural solution for a low-Q, short pulse, accelerating structure. In this case, all accelerating cells could be independent of each other (Fig. 1). This principle helps to reduce the breakdown influence and to increase shunt impedance, due to the smaller than usual beam pipe diameter of the structure. It is assumed that each accelerating cell has an individual coupler. This design is also appealing due to a low sensitivity to a cell's fabricated size. This is because a field in a given low-Q cell does not depend on the fields in all the other cells.

Necessary Cerenkov synchronism could be provided by utilizing a feeding antenna - combiner with a special bent design (Fig. 2). In this design, the radiation is distributed among 5 cells as a result of the bent blades. Figure 3 shows combiner antenna simulated together with accelerating structure at 11.7 GHz frequency. Key parameters of the structure are shown in the Table. 1. The S_{11} parameter for the feeding antenna without the structure is plotted in Fig. 4. An RF source, delivering 1 GW peak power in 1.4 ns pulses, can create a 300 MV/m accelerating field at axis.

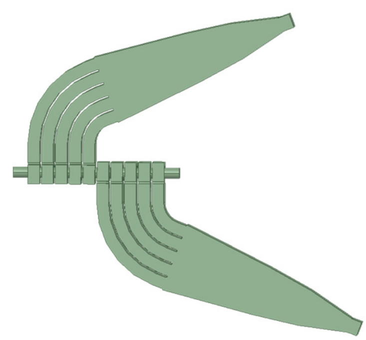

Figure 1: 5-cell side coupled accelerating structure.

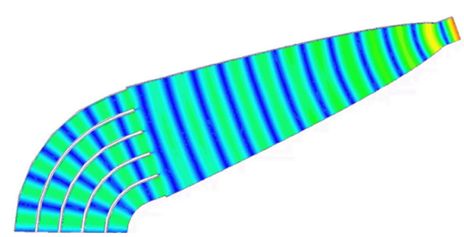

Figure 2: Instant E-field structure in feeding antenna.

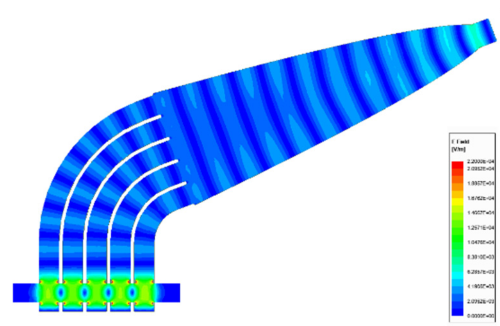

Figure 3: E-field distribution of the operating mode.

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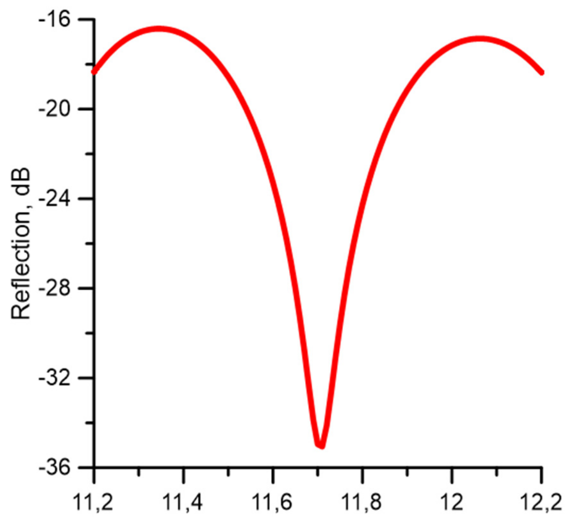

Figure 4: S_{11} parameter vs frequency.

Table 1: Parameters of the X-band 5-cell Structure

Parameter	Value
Frequency	11.7 GHz
RF pulse length	1.4 ns
Q-factor	50
Accelerator type	π-mode
Bending angle	69.2°
Cell length	26.6 mm
Beam channel	∅10 mm

AN 11.7 GHZ POWER EXTRACTOR FOR EXPERIMENT AT THE AWA FACILITY

We have designed an 11.7 GHz power extractor to be driven by bunch train at the Argonne Wakefield Accelerator Facility. This design exploits the ideas described in the introduction. Four independent pairs of cells have side-coupling with a combiner to connect pairs together (Fig. 5). The eigenmode is shown in the Fig. 6. It has accelerating fields of the opposite direction in neighboring cells and in-phase fields in cells separated by drift sections (Fig. 7). The fields in drift sections are low compared to fields in the accelerating cells.

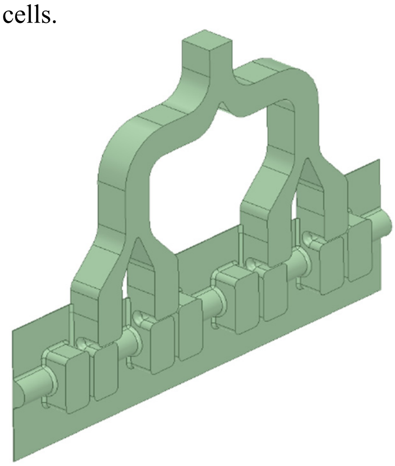

Figure 5: 11.7 GHz power extractor (a half of geometry).

The extractor was simulated so that it has the nearest spurious resonance at a frequency of 11.4 GHz, i.e. at 300 MHz less than the operating mode frequency (Fig. 8). Figure 8 was plotted given that we powered our extractor by a CW source located in the common upper waveguide port.

We plan to test this extractor at the AWA test facility. We simulated radiation production in the extractor by bunch train consisting of eight bunches. Bunch spacing corresponds to the 9th harmonics of the main 11.7 GHz frequency, which is a routing technique at AWA. For the 170 mm long extractor bunch diameter, 10 mm beam channel holes are required. This also constrains the maximum achievable shunt impedance and accelerating field magnitude.

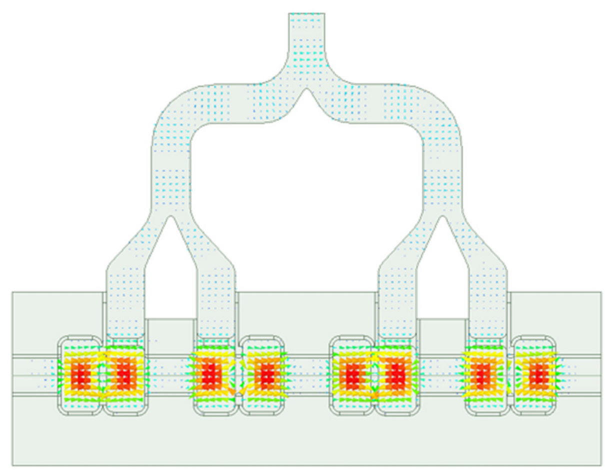

Figure 6: E-field distribution of operating mode.

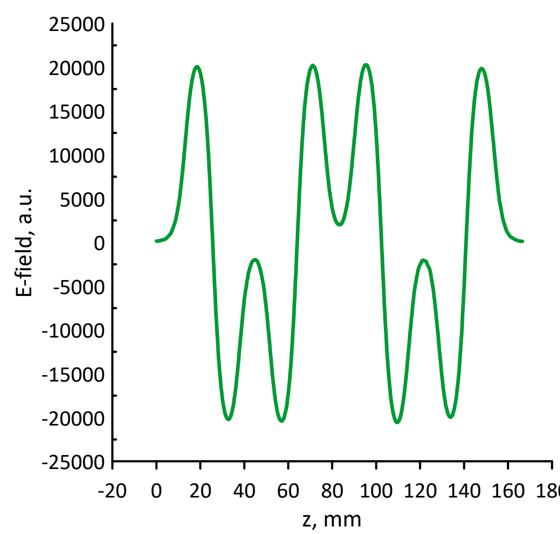

Figure 7: Accelerating field at axis of the extractor.

Field excitation by a high charge bunch train was simulated using CST Microwave Studio. We calculated the wake fields produced by a single bunch and then we simulated the superposition of wake fields produced by each of eight bunches. In Fig. 9, RF power, generated by one flying bunch, are shown with respect to time. Full RF power produced by the eight bunch contributors is represented in Fig. 10 for the two mentioned photocathode regimes.

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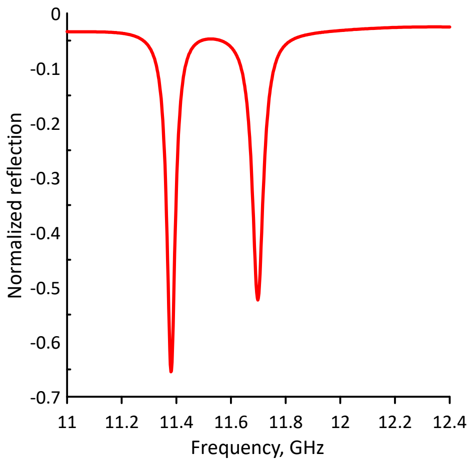

Figure 8: S_{11} parameter vs frequency.

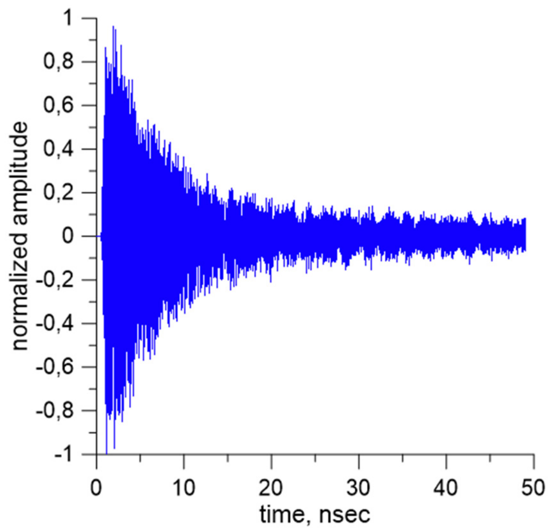

Figure 9: RF power in output of the extractor produced by single bunch.

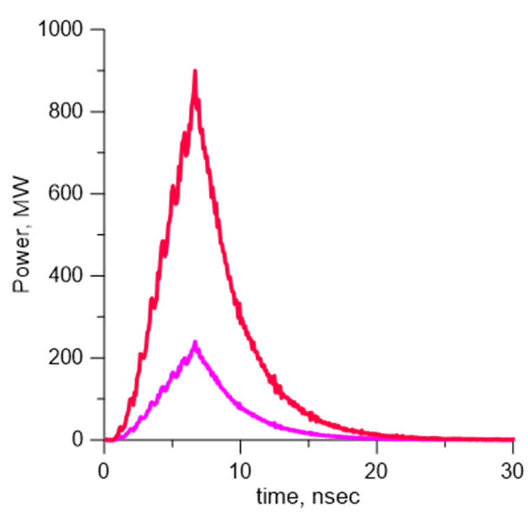

Figure 10: RF power envelope produced by eight 25 nC bunches (purple curve) and by eight 50 nC bunches (red curve).

One can see that it is possible to reach close to 1 GW RF power in a short pulse of triangular shape. The left front was determined to be a near linear power increase caused by consequent bunch entering the extractor. The rear front is the power decay in accordance with the cavity Q-factor. The key parameters for the extractor are summarized in Table 2.

Table 2: Parameters of the 11.7 GHz Power Extractor

Parameter	**25 nC**	**50 nC**
Q-factor	220	220
Bunch length	1.2 mm	1.8 mm
Surface E	530 MV/m	1030 MV/m
Surface B	1.23 MA/m	2.38 MA/m
Temperature rise	65°	240°
Shunt impedance	325 kΩ	325 kΩ
Pulse duration	10 ns	10 ns
Output power	240 MW	900 MW

The described extractor is under production now. We take advantage of split-block technology developed at Euclid Techlabs LLC [7].

CONCLUSION

The proposed short pulse accelerating structures allow for a considerable increase in the acceleration gradient. The design, based on RF power splitters, could be rather simple.

ACKNOWLEDGEMENT

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