DESIGN, FABRICATION AND LOW-POWER MEASUREMENTS OF AN X-BAND PARALLEL-COUPLED ACCELERATING STRUCTURE

Z. Huang, P. Huang, Y. Zhang, Y. Wei*, G. Feng
University of Science and Technology of China, Hefei, China

Abstract

This paper presents the design, fabrication and low-power measurements of an X-band parallel-coupled accelerating structure for short-pulse high-gradient applications. The structure, consisting of 16 cells fed in parallel by a smooth-waveguide network, is designed to operate under an input pulse length of 50 ns. Aluminum and copper prototypes were fabricated and cold-tested. The frequency deviation for each cell is tuned using bead-pull method, showing good agreement with the simulations.

INTRODUCTION

High-gradient RF accelerating structures are essential for compact accelerator systems such as X-ray FELs and future linear colliders. X-band technology enables gradients above 100 MV/m, but the breakdown rate strongly depends on both gradient and RF pulse length [1]. Reducing the pulse length is therefore critical for high-gradient operation [2].

Parallel-coupled accelerating structures provide an effective solution by distributing RF power directly to each cavity instead of relying on inter-cell coupling [3–5], allowing short filling time and flexible cavity design. In this paper, an X-band parallel-coupled structure based on a SLAC-type feeding topology is developed and experimentally tuned using the bead-pull method.

RF DESIGN

The structure consists of a feeding network and 16 accelerating cells, as shown in Fig. 1. The feeding network is formed by cascading 3-port smooth-waveguide T-junctions, which distribute RF power with a π phase difference between adjacent ports to match the π-mode operation.

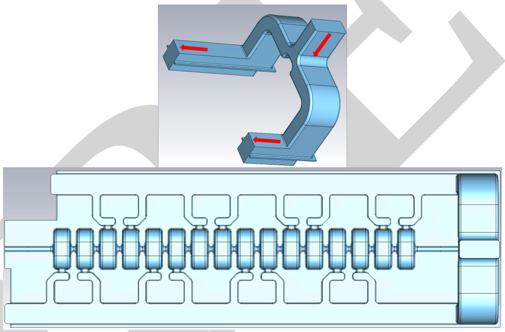


Figure 1: The geometry of the parallel-coupled structure with the coupler.

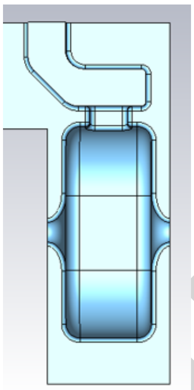


Figure 2: The geometry of the regular accelerating cell.

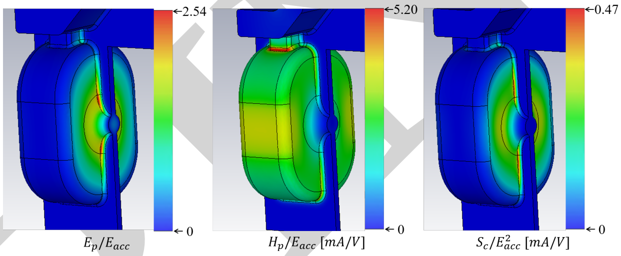


Figure 3: The normalized electric (a), magnetic (b) fields and modified poynting vector S_c (c) of the regular cell.

The regular cells adopt a racetrack-like geometry with a small iris aperture of 1.3 mm to achieve weak power coupling, as shown in Fig. 2. The electromagnetic field distributions of the regular cell is shown in Fig. 3. The parameters of the structure is shown in Table 1. The overall coupling coefficient is designed to be 4.8, corresponding to a filling time of approximately 40 ns.

Under this condition, the transient accelerating field can be approximately expressed as:

$$E_{acc} \propto \frac{2\sqrt{\beta'}}{1+\beta'}(1-e^{-t/t_f}) \tag{1}$$

where $t_f = 2Q_0/\omega(1+\beta')$ is the filling time determined by the coupling coefficient β' of the full parallel-coupled structure, which is defined by:

$$\beta' = 2N\frac{1-|s_{33}|}{1+|s_{33}|}\beta \tag{2}$$

where β, N are the coupling coefficient and number of the regular cells.

The simulated on-axis field distribution is shown in Fig. 4. It can be observed that the 1# and 16# cells should be tuned a little due to the power coupling.

---

* wylong@ustc.edu.cn

Table 1: Parameters of the Parallel-Coupled Structure

Parameters	**Value**	**Unit**
Operating frequency f	11.424	GHz
The number of cells	16	
Required input power	108	MW
Accelerating gradient	140	MV/m
Shunt impedance R_s	105.1	MΩ/m
Quality factor Q_0	7930	
Coupling coefficient β	1.66	
Overall coupling coefficient β'	4.78	
Filling time τ	40	ns
RF pulse length t_p	50	ns

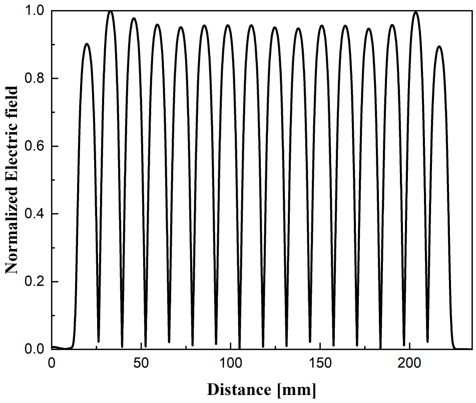


Figure 4: The simulated on-axis field distribution.

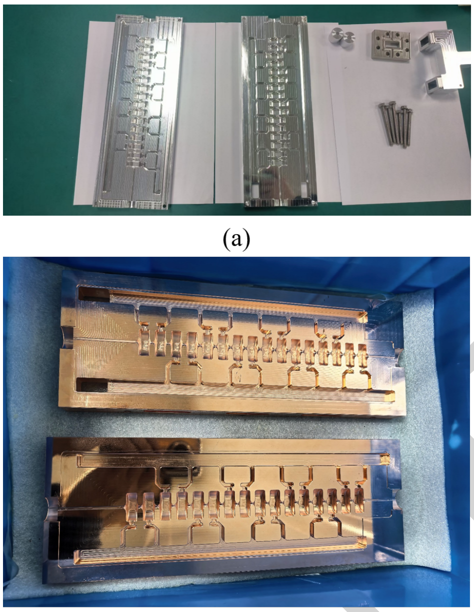
FABRICATION AND LOW-POWER TEST

Two prototypes have been fabricated: an aluminum prototype for machining verification and a copper prototype for tuning and subsequent high-power testing, as shown in Fig. 5. All the measurements are conducted in a laboratory with constant temperature and humidity, with an temperature of $21^{\circ}C$ and a relative humidity of 40%. The structure is filled with air during the measurement process.

The aluminum prototype has been measured by the bead-pull method [6–8]. The results shows a good field flatness, corresponding to machining errors below 5 µm, as shown in Fig. 6.

The copper prototype has been brazed at high temperature of 800 °C. Due to the relatively lower mechanical rigidity compared to the aluminum alloy, multiple clamping fixtures are employed during the brazing process to ensure the bonding quality. As a result, the prototype experiences a certain degree of deformation during machining, annealing and brazing, as shown in Fig. 7. After preliminary tuning, the bead-pull results are shown in Fig. 8.

After iterative tuning using the bead-pull method, the field flatness is significantly improved, as shown in Fig. 9. And the final S parameters are shown in Fig. 10, corresponding to a coupling coefficient of 4, closely to the designed value. These results satisfy the requirement of the high-power test operating at short pulse.



(a)

(b)

Figure 5: Aluminum and copper prototypes before brazing.

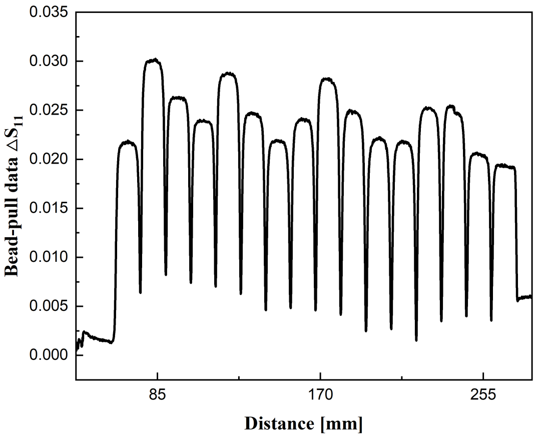


Figure 6: The bead-pull result for the aluminum prototype.

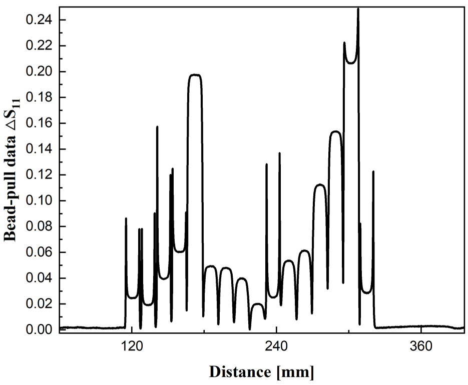


Figure 7: The bead-pull result for the copper prototype before tuning.

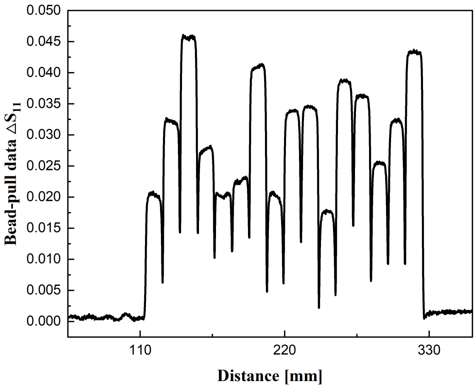


Figure 8: The bead-pull result for the copper prototype after preliminary tuning.

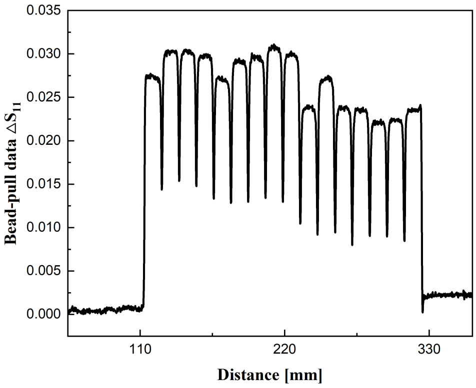


Figure 9: The bead-pull result for the well-tuned copper prototype.

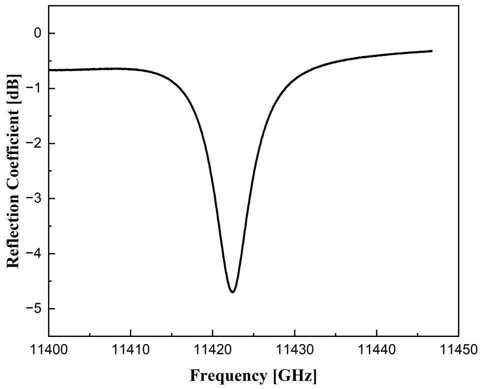


Figure 10: The S parameters for the well-tuned copper prototype.

CONCLUSION

An X-band parallel-coupled accelerating structure has been designed, fabricated, and tested under low-power condition. The aluminum and copper prototypes have been measured by the proposed method and the copper prototype has been well tuned using the bead-pull method other than the metallic plunger. The results demonstrate the fabrication errors satisfy the tolerance requirements, demonstrating the feasibility of this structure for short-pulse high-gradient applications and provide a basis for future high-power tests.

ACKNOWLEDGMENT

This work is supported by the Fundamental Research Funds for the Central Universities (No. WK2310000114), the “Hundred Talents Program” of the Chinese Academy of Sciences (No. KJ2310007003), Chinese Academy of Sciences President’s International Fellowship Initiative (No. 2025PD0102).

REFERENCES

[1] A. Grudiev, S. Calatroni, and W. Wuensch, “New local field quantity describing the high gradient limit of accelerating structures,” *Phys. Rev. ST Accel. Beams*, vol. 12, p. 102001, 2009. `doi:10.1103/PhysRevSTAB.12.102001`

[2] G. Rijal, M. Shapiro, and X. Lu, “Analytical and numerical studies of dark current in radiofrequency structures for short-pulse high-gradient acceleration,” *Phys. Rev. Accel. Beams*, vol. 28, p. 111301, 2025. `doi:10.1103/w9mh-3klh`

[3] W. Gu *et al.*, “Design, fabrication, and test of a parallel-coupled slow-wave high-gradient structure for short input power pulses,” *Phys. Rev. Accel. Beams*, vol. 28, p. 060401, 2025. `doi:10.1103/dqpb-hst9`

[4] 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`

[5] Y. Jiang *et al.*, “Analysis and design of parallel-coupled high-gradient structure for ultrashort input power pulses,” *Phys. Rev. Accel. Beams*, vol. 24, p. 112002, 2021. `doi:10.1103/PhysRevAccelBeams.24.112002`

[6] T. P. Wangler, *RF Linear Accelerators*, 2nd ed., Wiley-VCH, 2008. `doi:10.1002/9783527623426`

[7] J. C. Slater, “Microwave electronics,” *Rev. Mod. Phys.*, vol. 18, no. 4, pp. 441–512, 1946. `doi:10.1103/RevModPhys.18.441`

[8] C. W. Steele, “A nonresonant perturbation theory,” *IEEE Trans. Microwave Theory Tech.*, vol. 14, no. 2, pp. 70–74, 1966. `doi:10.1109/TMTT.1966.1126168`