DEVELOPMENT OF AN X-BAND METALLIC POWER EXTRACTOR FOR THE ARGONNE WAKEFIELD ACCELERATOR

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Abstract

An X-band (11.7GHz) power extractor has been developed for RF power generation at Argonne Wakefield Accelerator (AWA). The structure is a 2π/3-mode disk-loaded structure with group velocity of 22% of the speed of light and a total length of about 300mm. It is build with copper disks brazed together. This note presents the design and the fabrication of this structure, as well as the RF measurement results.

INTRODUCTION

RF power can be extracted from the wakefield generated by a relativistic charged particle beam. Because transverse wake forces may cause beam instabilities, the wakefields induced by beams in the various accelerating structures have been under extensive study since the beginning of the field of accelerator physics [1, 2, 3, 4, 5]. Apart from its harmful effects on particle acceleration, in recent decades there has been considerable research that attempts to take advantage of the strong longitudinal wakefield generated by high current beams [19-23]. Typical examples are the 30 GHz (later 12 GHz) Two Beam Accelerator (TBA) concept developed at CERN [6, 7] and the dielectric based wakefield accelerator at ANL [8, 9]. In addition, independent dielectric based wakefield power extractors working at different frequencies have also been studied in recent years [10].

Wakefield power extraction uses a slow wave structure in which the electron beam interacts with the impedance of the structure and excites a preferentially synchronous waveguide mode. In the process, the beam kinetic energy is converted into electromagnetic energy at the mode frequency. The RF power produced is collected at the downstream end of the structure and coupled out for other applications.

Benefiting from the $\sim$10 GW beam power provided by the high current linac at the Argonne Wakefield Accelerator (AWA) facility, a series of high power RF sources has been planned based on the extraction of coherent Cherenkov radiation from relativistic electron beams. The frequency spectrum of AWA beam (from the 1.3 GHz injector) covers up to W-band without the need for a complicated beam compression system. Simulations show that $\sim$1 GW, 20 ns RF pulses can be generated using an 11.7 GHz structure. The pulse length is expandable to 50 ns with a lower peak power. This note describes the RF design and the fabrication of an X-band (11.7GHz) power extractor.

DESIGN OF THE STUCTURE

The Slow-Wave Structure

The X-band (11.7 GHz) metallic wakefield power extractor is a constant impedance 2/3 mode disc-loaded structure (working as a decelerator in this case). It has a group velocity of 22% of the speed of light to match the bunch spacing of the AWA beam. A sketch of a section of the decelerator is shown in Figure 1. The high power RF pulse output is through the WR-90 waveguide of the coupler.

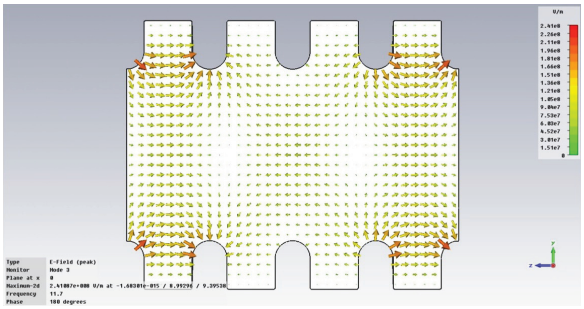

Figure 1: RF design of the disk-loaded 2π/3-mode structure.

Frequency of the decelerator is determined by the bunch spacing. The AWA beam is produced by a 1.3 GHz photoinjector so that the operating frequency of the X-band wakefield power extractor is chosen to be 11.7 GHz, the ninth harmonic of 1.3 GHz. We chose the conventional $2\pi/3$ mode for high R/Q. The effective structure length is $\sim$30 cm and the group velocity is 0.22c, resulting in 5 overlapped bunches and a rise time t_r of 3 ns (calculated by $t_r = (5-1) \times T_b$, where T_b is the bunch spacing and $T_b = 769$ps for the AWA beam).

The phase velocity has to be the speed of light. With a phase advance of 120 degrees, the cavity length is 8.54 mm so that a total of 35 cells is needed to reach the 30 cm ef-

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fective length. The thickness of the disks is 3.6 mm to give a reasonable E-field on the surface of the iris. The diameter of the beam opening is 17.6 mm, which is fairly large in order to pass a reasonable amount of charge without a built in complicated transverse mode damping feature. A 3-cell accelerating structure (no damping) with a beam hole of ~8 mm was tested at AWA years ago. A 15 MeV bunch with 25 nC charge (the largest available charge at that experiment) was launched with 100% transmission. We expect a bunch train consisting of up to 16 bunches with 50 nC/bunch to pass through a 30 cm long, 17.6 mm beam hole for this proposed X-band wakefield power extractor in the AWA new 75 MeV beamline. Figure 4 shows the E-field pattern of a section of decelerator. Table 1 shows the main parameters of the structure. The transverse wakefield damping may be included in the future upon results of the first beam experiment.

Table 1: RF Design of the Structure

parameters		value
frequency	f_0 (GHz)	11.7
phase advance	φ (DEG)	120
aperture diameter	$2a$ (mm)	17.6
group velocity	v_g/c	0.22
shunt impedance	R/Q (kΩ/m)	3.92
length	L (cm)	30
quality vactor	Q	6500

The power extracted from a relativistic bunch train can be calculated as [11]:

$$P = \frac{\omega}{4c}\left(\frac{R}{Q}\right)\frac{l_s^2 I^2}{\beta_g}F^2(\sigma)\left(\frac{1-e^{-\alpha l_s}}{\alpha l_s}\right)^2, \qquad (1)$$

where l_s is the length of the structure; I is the average current defined by the ratio of the bunch charge q_b to the bunch spacing T_b; and $\alpha = \omega/2Qv_g$ is the attenuation factor. $F(\sigma)$ is the form factor of the bunch, which can be expressed as $F_\sigma = \exp[-(k\sigma)^2/2]$ for a relativistic Gaussian bunch; k is the propagation constant of the excited mode and σ is the bunch length. Plugging the parameters shown in Table 1 into Equation (1), we can calculate the RF power extracted from the available beam power. Table 2 shows the estimated power and peak E-field on the iris with different charge per bunch in the bunch train.

Table 2: Output Power of 11.7GHz Metallic Power Extractor

parameters		value		
Charge/bunch	q (nC)	20	40	50
Bunch length	σ_z (mm)	2	2.3	2.3
RF power	P (MW)	51	187	293
Peak surface field	Es (MV/m)	30	57	72
Max. energy loss	E_{loss} (MeV)	4	7.6	95

A matching cell is added at the end of this structure to match the slow-wave periodic structure to the circular waveguide. The power will further be transmitted through a $\text{TM}_{01}{}^{\circ}$-to-TE_{10} mode-launcher to a rectangular waveguide WR90. The mode-launcher or the coupler will be discussed in the follow subsection.

The Coupler

The coupler for the X-band metallic power extractor uses a dual port scheme to suppress the beam induced deflecting mode. The model in CST[12] and the simulated S-parameters are plotted in Figure 2, which shows that the well-matched bandwidth exceeds 500 MHz. The peak electric field is 27 MV/m in the coupler when 300 MW power is transported. It has a considerable safety margin for a short pulse length ($<$ 50ns).

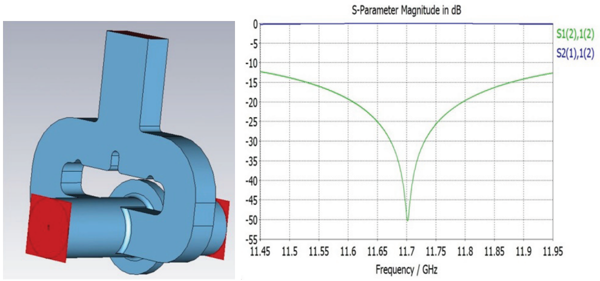

Figure 2: RF design (left) and the simulated S-parameters (right) of the coupler in CST Studio Suite.

DEVELOPMENT OF THE STRUCTURES

Engineering Design

The structure is build by disks and they are brazed together as a sealed structure. Since no damping waveguides or slots are applied to the cavity walls, the disks are fabricated only by turning. Giving the tolerance of 10μm for the radii, the frequency variation of the cells is about 10MHz, which would cause 0.5 degree phase error per cell. No tuning features are added to the outside wall in order to ease the fabrication. The overall phase advance can be controlled by tuning the frequency with the operating temperature of the whole structure more precisely.

The coupler is fabricated by milling the inside shape and brazing two parts together. All the WR90 waveguides and the beam-pipes are then brazed afterwards. The coupler is connected to the structure with the SLAC circular waveguide flange, and this coupler is reusable if another 11.7-GHz power extractor is made.

RF Measurement

RF measurement is made before brazing to check the quality of the fabrication. The two couplers are clamped directly and the S-parameters are measured, to be sure no mistakes were made when making drawings or programming the milling machine to make this complicated shape. Instead of -50dB in simulation, we obtain about

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-25dB of reflection, which is acceptable. The disks are also clamped together between the two couplers to measure the S-parameters for a quick check. The transmission is greater than -0.6dB, indicating a good $Q(\sim 4000)$ is already achieved only by clamping.

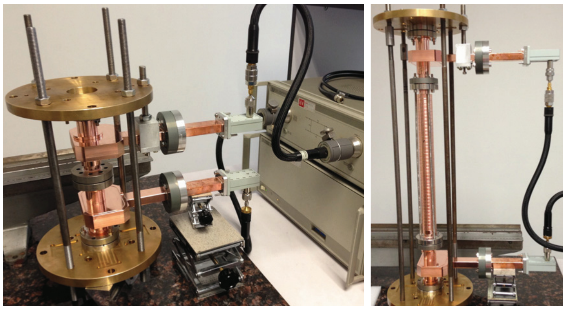

Figure 3: RF measurement setup before brazing (by clamping the couplers and/or the disks); Left: RF check of coupler-coupler, Right: RF check of the disks

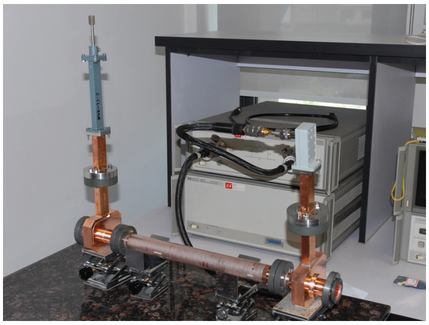

Figure 4: RF Measurement Setup after Brazing

Another RF measurement is carried out after all brazing (Figure. 4) and the results are plotted in Figure 5. From the reflection and the transmission, this structure is quite nice. The measured group delay of this configuration is 8 ns. Subtracting the group delay measured with only two couplers, which is 3 ns, we can calculate the filling time of the structure to be 5ns which agrees with the simulated group velocity. A bead-pull measurement is planned to obtain the field profile on axis, to calculate the phase advance per cell or the phase velocity.

CONCLUSION

An X-band metallic power extractor build has been developed for the power generation at Argonne Wakefield Accelerator (AWA). This structure is made of copper disks brazed together as a self-sealed tube. Measurement of the S-parameters shows good RF performances. And the experiment to generate high RF power with this structure is planned in the coming months.

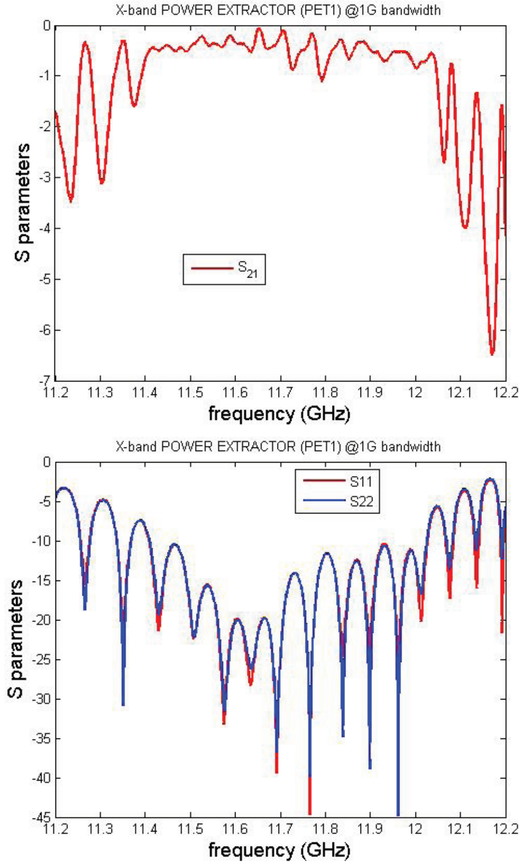

Figure 5: Transmission (top) and reflection (bottom) after brazing.

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