HIGH POWER TESTS OF A HIGH-EFFICIENCY C-BAND TRAVELING-WAVE ACCELERATING STRUCTURE

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Abstract

In order to realize a compact scheme and high accelerating efficiency for the linear injector of the proposed Jinhua light source (JHLS) project, a 1-meter constant gradient (CG) C-band traveling-wave (TW) accelerating structure has been developed and constructed to achieve a high acceleration gradient of > 50 MV/m . This C-band accelerating structure operates at $3\pi/4$ mode and achieves an average shunt impedance of 94 M/m through optimization. After tuning process, the cold-test measurement results of this accelerating structure are in good agreement with the simulated values. In high-power tests, this structure was fed into an average power of 32 MW(equivalent to an output power of 37.7 MW from the klystron) with a pulse width of 300 ns. Therefore, an unloaded gradient of 41.6 MV/m was achieved at a breakdown rate of less than 1×10^{-5} breakdown per pulse meter (bppm). A further high-power tests are expected to achieve an average gradient of > 50 MV/m in the next step.

INTRODUCTIONS

The Jinhua light source (JHLS) is a proposed synchrotron radiation facility to be built at Jinhua, Zhejiang, China, in order to meet the increasing requirement of user demands for industrial applications. It consists of a linear injector, a booster, and a storage ring. The injector is designed to produce a high-quality beam with an energy of 150 MeV, which is then injected into the booster and storage ring to reach a final energy of 2.6 GeV. Table 1 summarizes the basic beam parameters of the JHLS injector.

Table 1: Beam Parameters of the Injector in JHLS

Parameter	Value	Unit
Beam Energy	150	MeV
Bunch Charge	0.3 ~ 1	nC
Bunch Length (RMS)	≤ 10	ps
Transverse Size (RMS)	0.5	mm
Repetition Rate	≤10	Hz
Emittance (RMS)	≤60	mm·mrad
Energy Spread (RMS)	≤ 0.5%	-

In order to achieve the target energy within a limited distance, a high-gradient accelerating structure is essential to achieve a compact accelerator scheme and cost-effectiveness. However, the stronger electromagnetic fields on the surface of such a structure will inevitably lead to pulsed heating and a higher radiofrequency (RF) breakdown rate (BDR). Moreover, for periodic traveling-wave accelerating structures, a higher shunt impedance and a lower group velocity yield a higher accelerating gradient under a given input power. Taking into account the trade-offs and interactions among accelerating gradient, structural dimensions, and BDR, we have develop a C-band constant-gradient traveling-wave accelerating structure [1]. The content of this paper is organized as follows. Section II briefly presents the RF design of this C-band accelerating structure. Section III introduces the fabrication and the cold-test measurement. Section IV presents the high-power tests of this C-band structure. Finally, Section V summatizes this paper.

RF DESIGN

The working mode of phase advance determines its dispersion curve and directly influences parameters such as group velocity, quality factor, and shunt impedance. We have analyzed and compared the RF parameters of the accelerating structures under different working modes, within the constant cavity iris and and disk thickness, as presented in Table 2. It is notable that the $3\pi/4$ working mode is chosen due to a trade-off between the available shunt impedance and the filling time for our C-band structure.

Table 2: Comparison Between Different Working Modes

Parameter	$2\pi/3$	$3\pi/4$	$4\pi/5$
Frequency (GHz)	5.712	5.712	5.712
Quality factor	11011	11991	12585
v_g/c (%)	1.469	1.199	0.990
R_s M/m	92.7	93.9	93.1

Aiming to minimize the surface electric field while enhancing the shunt impedance, the regular cells are performed to be optimized with an elliptical iris and arc-shaped tops. Meanwhile, a racetrack-type coupler incorporating a short-circuited waveguide was employed to suppress the multipole field components effectively. This RF design is described in detailed in [1]. In summary, this C-band accelerating structure consists of 44 regular cells with iris radius tapered from 6.25 mm down to 5.23 mm to realize a low-group velocity from 1.6%c down to 0.86%c. When feeding into an input power of 29.6 MW, an average unloaded gradient of 40 MV/m can be realized for this prototype. At this gradient, the maximum surface electric field $E_s = 87.4$ MV/m and the modified Poynting vector [2] $S_c = 3.4$ MW/mm^2. The pulsed heating can be calculated by the following for-

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mula [3]:

$$T = 127|H_\mathrm{s}|^2\sqrt{f t_\mathrm{p}}. \tag{1}$$

Therefore, the corresponding temperature rise is calculated to be 13 K under an input pulse length of $t_\mathrm{p} = 300$ ns, much lower than the empirical thresholds of the C-band structures.

COLD-TEST MEASUREMENT AND TUNING

This C-band accelerating structure prototype is composed of oxygen-free copper disks, which were individually lathed and then brazed together. The prototype were cold-tested and tuned after brazing,with the nodal-shift method employed during the tuning procedure.

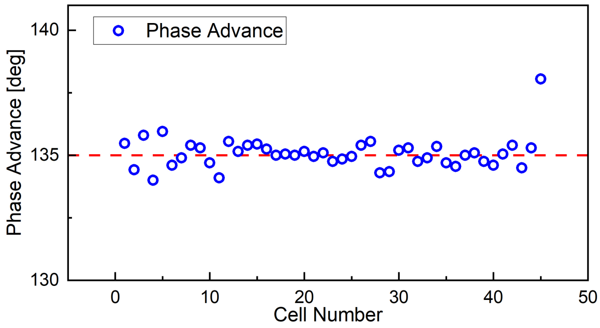

Figure 1: Phase advances between adjacent cells after tuning.

Following tuning, the measured phase advances of the adjacent cells were maintained at 135°, with a maximum error of less than 1°, as shown in Fig. 1. The on-axis electric field distribution measured using the bead-pull method [4,5] is presented in Fig. 2.

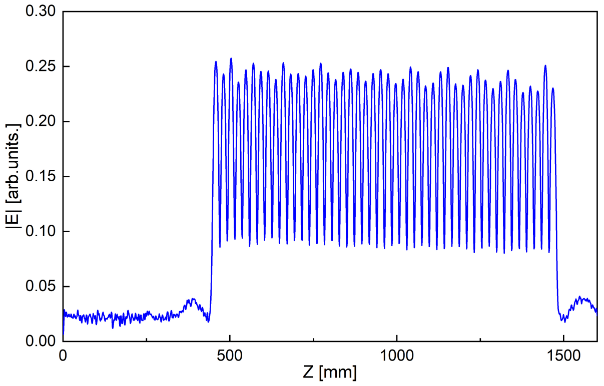

Figure 2: Relative magnitude of the electric field along the beam axis.

The measured S_{11} and S_{21} are −43 dB and −3.48 dB,respectively. The filling time was calculated to be $t_\mathrm{f} = 255.5$ ns. All measured results show good agreement with the simulated values.

HIGH-POWER TESTING

This C-band TW accelerating structure was high-power tested in the C-band test platform at the Spallation Neutron Source Science Center, Dongguan City, Guangdong Province, as shown in Fig. 3. The C-band klystron provides a peak output power of 50 MW and a pulse width of 2.5 μs with a repetition rate of 10 Hz.

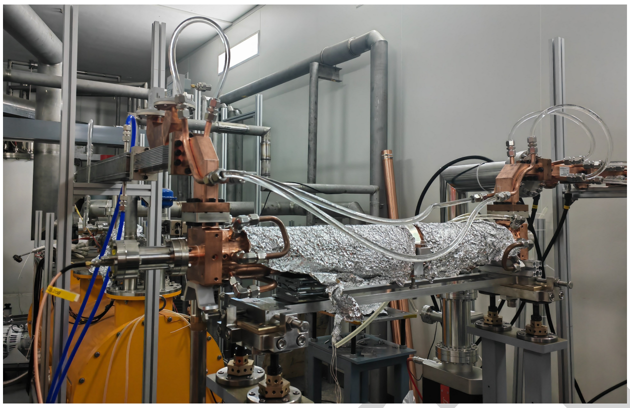

Figure 3: High-power tests in the C-band test platform.

Due to the limitation of the platform, the high-power testing was performed by manual conditioning instead of through the low-level radio frequency control system. The conditioning was performed by the following progress. At Stage I, the klystron began with a low power level of <15 MW and a long pulse width of 0.8 μs. At Stage II, the pulse width was reduced to 500 ns while the power was progressively increased to 30 MW. At stage III, the output pulse width was reached the target of 300 ns, while the input power was raised to the maximum achievable level.

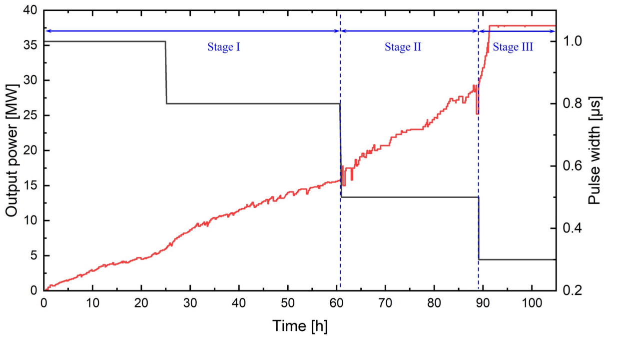

Figure 4: The output power and output pulse width curve of the klystron.

The output power and the pulse width variation of the klystron are shown in Fig. 4 . The vacuum history during the conditioning process is shown in Fig. 5. It can be seen that in Stage III the RF breakdown was weakened while the power increased rapidly because of the short pulse width.

After reached a klystron power level of 37.7 MW, this C-band structure has been tested maintaining this power for more than ten hours at 10 Hz, corresponding to 4.8×10^5 pulses.The BDR is caluclated to be $< 9 \times 10^{-6}$ bppm. The output pulse waveform is shown in Fig. 6.

Due to the constraints of the experiment time and the other tasks scheduled on this platform, the conditioning was terminated. Therefore, the maximum incident power for the accelerating structure has reached 32 MW, considering the

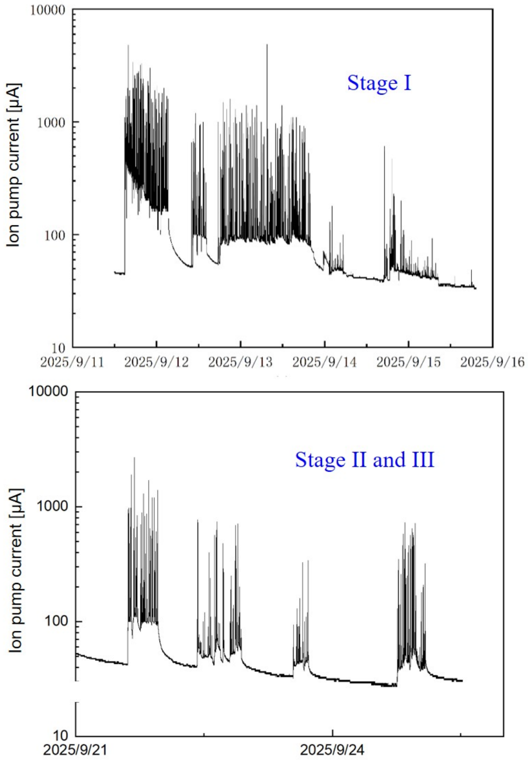

Figure 5: The vacuum history during the high-power testing.

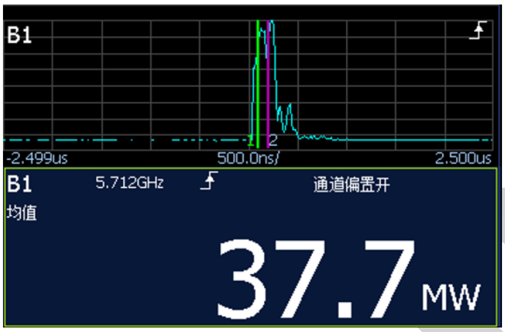

Figure 6: Output pulse waveform at the maximum power level.

non-negligible RF loss results from the long waveguide system. Under this situation, this C-band structure was enable to realize an average accelerating gradient of 41.6 MV/m, which has shown an excellent power efficiency. However, it can be expected that this C-band structure will reach a higher gradient level of over 50 MV/m, if the C-band pulse compressor is utilized to enhance the klystron power. After high-power tests, this structure was cold-measured again to examine the .The S_{11} and S_{21} are measured to be −38 dB and −3.46 dB, respectively, which demonstrated the operation stability under high-power conditions.

CONCLUSION

In this paper, a 1-m high-efficiency C-band CG TW accelerating structure operating at $3\pi/4$ mode has been developed at NSRL, USTC, for the JHLS project. Such a structure is designed to generate an accelerating gradient of 40 MV/m with an input power of 29.6 MW. The regular cell are optimized with an elliptical isires and arc tops, in order to reach an maximum shunt impedance of 93.9 M/m and reduce the peak surface field. The cold-test measurement after tuning has shown good agreement with the simulated values. In the high-power tests, an input power of 32 MW with a pulse width of 300 ns was fed into the accelerating structure, thereby realizing an average accelerating gradient of 41.6 MV/m. Due to the restriction of the klystron power and the RF load power, the conditioning was terminated. However, the high-power results has demonstrated an excellent power efficiency for this C-band structure. It is ready for combing with the pulse compressor to reach a higher gradient of 50 MV/m in the next step.

ACKNOWLEDGMENT

The authors would like to thank Dr. Mi Hou at IHEP, Beijing, China for fruitful discussions, Dr. Xingguang Liu, Hui Zhang, and Dr. Shimin Jiang at IHEP for the high-power tests support. This work is supported by the “Hundred Talents Program” of Chinese Academy of Sciences (Grant No. KJ2310007003), the Fundamental Research Funds for the Central Universities (Grant No. WK2310000114) and Chinese Academy of Sciences President’s International Fellowship Initiative (Grant No. 2025PD0102).

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