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HIGH POWER TEST OF THE FIRST C-BAND SPHERICAL PULSE COMPRESSOR PROTOTYPE*

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Abstract

Recently, a new C-band (5712 MHz) compact spherical radio frequency (RF) pulse compressor was designed and tested for Shanghai Soft X-ray Free Electron Laser Facility (SXFEL). This pulse compressor utilizes one high Q_0 spherical RF resonant cavity that works with two $TE_{1,1,3}$ modes and a dual-mode polarized coupler. The peak power multiply factor is 6.1 and average power gain 3.8 in theory. During the high power test, a peak power multiply factor of 5.74 and average power gain of 3.77 was achieved. This paper presents the RF measurement of the C-band spherical pulse compressor and the high power test results.

INTRODUCTION

The first stage (Phase-I) of Shanghai Soft X-ray Free Electron Laser facility (SXFEL) was accomplished in 2017 with electrons successfully accelerated to 0.84 GeV. In the main accelerating section, the C-band SLED-type pulse compressors [1, 2] played a significant role in multiplying the input power of accelerators. However, due to its two large resonant cavities, SLED is relatively large. Moreover, SLED requires two supplementary advanced chillers for the two cavities, which makes it uneconomical and complicated. Currently, the SXFEL linac energy is being upgraded to 1.5 GeV (Phase-II) by cascading more C-band accelerating structures. In Phase-II, pulse compressors are still needed because of its high cost performance.

In 2014, A new pulse compressor based on only one spherical cavity was proposed and developed for the Linac Coherent Light Source (LCLS) X-band linac linearizer at SLAC [3, 4]. This compact spherical pulse compressor scheme employed one spherical cavity with two polarized spherical $TE_{1,1,4}$ modes and a dual-mode polarized coupler. Based on this design, the resonant frequencies of the two polarized modes can be easily tuned to the same one. More importantly, the frequency of the two modes varied by the same number when the temperature fluctuated during operation, which can make the output power of the pulse compressor stable when working. Consequently, this type of pulse compressor is very compact and operated stably with a simple cooling system. We hence selected the spherical pulse compressor as an upgrade of our SLEDs. Based on the X-band spherical pulse compressor, the present study generates a similar design for the C-band pulse compressor for SXFEL energy upgrading using $TE_{1,1,3}$ modes. The chosen modes can make the pulse compressor reasonably compact while maintaining a high energy gain. The RF design of this C-band spherical pulse compressor has been carried out in references [5, 6]. In this paper, we present the results of RF measurement and high power test.

RF MEASUREMENT

The pulse compressor's performance of RF parameters was measured before and after brazing using a vector network analyzer to ensure the machining parameters were correct.

Coupler

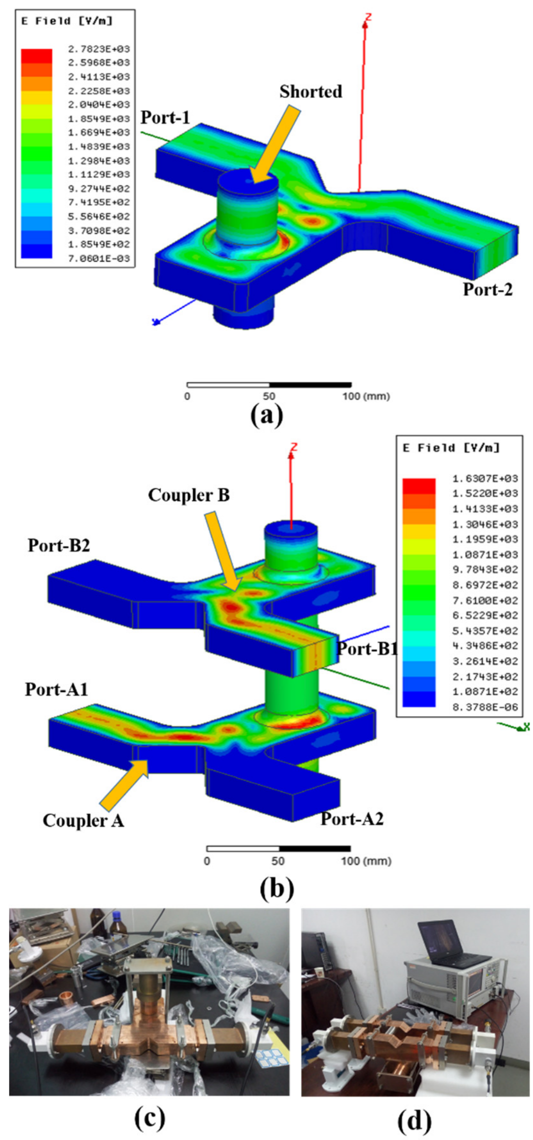

Figure 1: Two methods of measuring the coupler: (a) short-circuiting the circular waveguide and (b) connecting two couplers to form one through the circular waveguide. (c) and (d) are the corresponding physical setup.

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The circular waveguide of the coupler, which connects the coupler and cavity, has a non-standard waveguide port. There is no standard coaxial-to-waveguide adapter with its diameter. Therefore, the coupler must be measured indirectly. Given the two TE_{11} modes in the circular waveguide, there are two methods available. One is to short-circuit the circular waveguide port as shown in Fig. 1(a). In this case, all power will be reflected back to the coupler. With a 90° phase difference, the two reflected TE_{11} modes will be reunited into one rectangular waveguide TE_{10} mode and extracted from the output port (Port-2). The other method is to connect two identical couplers A and B through the circular waveguide. For power comes from Coupler A, the two polarized TE_{11} modes in the circular waveguide will be led to Coupler B and emitted from one of its two rectangular waveguide ports, Port-B1. Figure 1(b) shows the power flow when two couplers were connected.

Two couplers were measured using both methods mentioned above as shown in Fig. 1(c) and (d). Table 1 summarizes the measurement results. Both the two couplers have a reflection less than −25 dB and a transmission of about −0.13 dB, indicating a good RF performance.

Table 1: Measurement Results of Couplers

S-Para. [dB]	Coupler-A	Coupler-B	(A&B)
S_{11}(S_{11})	−28.33	−28.11	(−30.1)
S_{21}(S_{21})	−0.13	−0.11	(−37.88)
S_{12}(S_{31})	−0.13	−0.13	(−0.24)
S_{22}(S_{41})	−31.33	−22.77	(−35.65)

Cavity and the Pulse Compressor

The cavity cannot be measured individually because of its non-standard coupling aperture. Therefore, it must be measured together with the coupler, which also gives the results for the entire model. Figure 2(a) shows the prototype and Fig. 2(b) shows the physical setup of cavity and pulse compressor measurement.

According to the first RF measurement, the reflection of this prototype was −8.6 dB, which was too large to run. In the spherical pulse compressor, a big reflection is because of the frequency difference between two degenerated $TE_{1,1,3}$ modes in cavity. This can be solved by slightly changing the cavity shape. We therefore machined several tuning holes on the equatorial plane of the cavity. Finally, the reflections on both rectangular waveguide ports were tuned to less than −30 dB as shown in Fig. 2(c). S_{21} shown in Fig. 2(d) was −4.3 dB, giving a coupling coefficient of 4.2 and a quality factor of 91000. The coupling coefficient and Q-factor were smaller than the designed ones, which will affect the compression performance. The energy multiply factor and average power gain were recalculated using the measured results and the updated ones were 1.83 and 3.68, respectively, which could still satisfy our needs.

The overall size of this prototype in Fig. 3 is approximately 400 mm × 280 mm × 210 mm, which for C-band SLED used on SXFEL Phase-I is 780 mm × 690 mm × 210 mm. The spherical pulse compressor is much more compact than SLED.

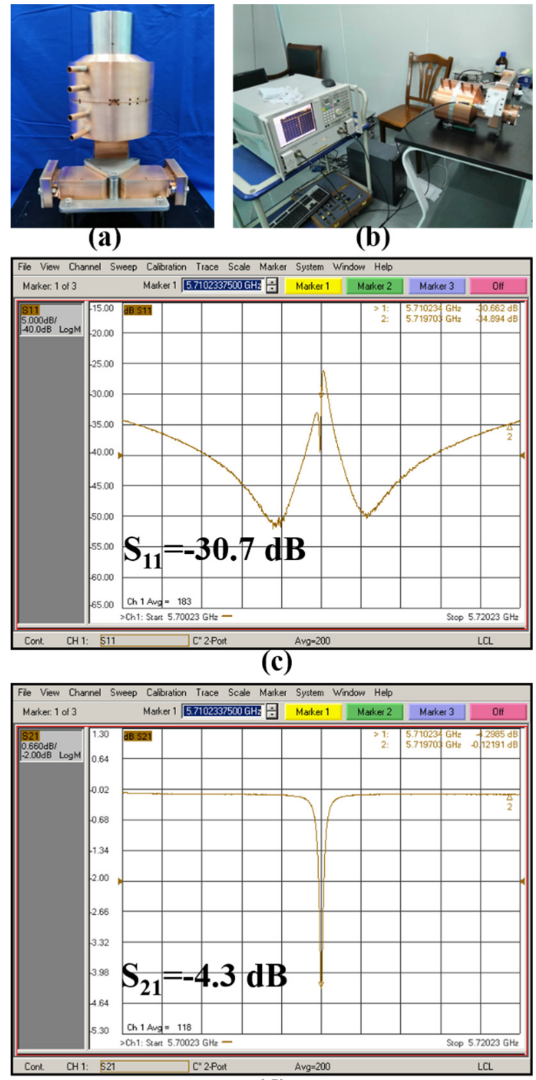

Figure 2: (a) Spherical pulse compressor prototype, (b) RF measurement of the prototype, (c) the reflection is -30.7 dB and (d) the transmission is -4.3 dB after tuning.

COLD AND HIGH POWER TESTS

Cold Test

Before engaging high-power operation, a cold test system was set up to check the working conditions of the spherical pulse compressor with inversed input power. Figure 3(a) shows the cold test system. Instruments in the cold-test system included a BNC 575 pulse generator, RF source, phase reverser, oscilloscope, and power meter.

Figure 3(b) shows the waveforms of the C-band spherical pulse compressor on an oscilloscope. The green curve is the output pulse, while the pink one is the input one. The peak power gain is measured using a power meter. According to the power meter readings, the peak output power is 6.64 dBm while input power is −1.17 dBm, giving a peak

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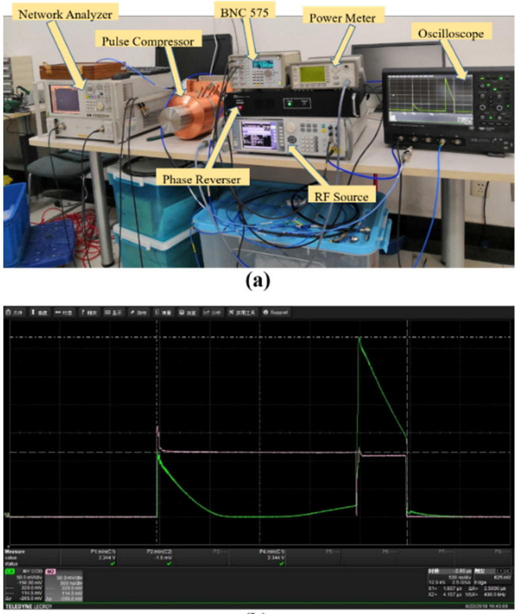
power gain of 6.04, which is very close to the designed value of 6.1.

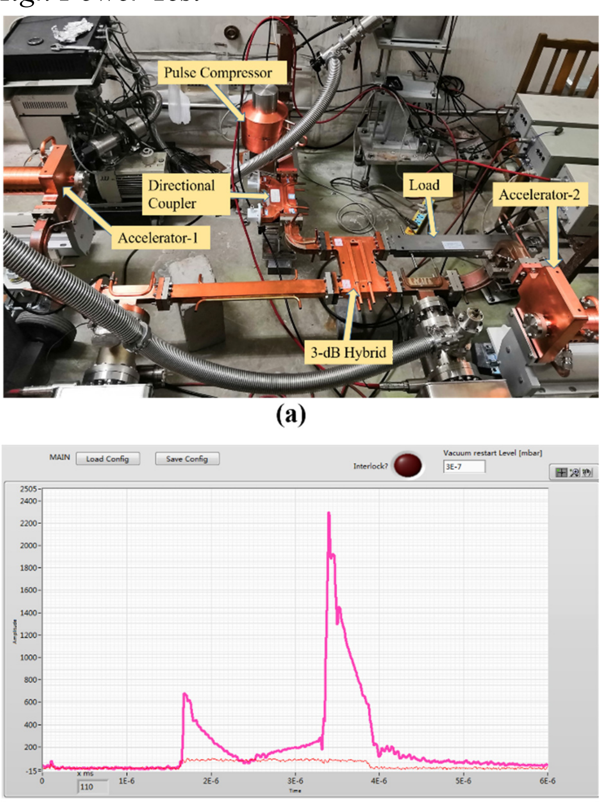


(a)

(b)

Figure 3: (a) Cold test and (b) the input (pink curve) and output (green curve) waveform.

High Power Test



(a)

(b)

Figure 4: (a) High power test and (b) the input (orange curve) and output (red curve) waveform, the two curves are in different unit, which makes the input signal small.

The high power test was carried out in Shanghai Deep Ultra Violet Free Electron Laser (SDUV-FEL) tunnel, including a C-band klystron, the spherical pulse compressor, two accelerators, the waveguide system and LLRF system. Figure 4(a) shows the high power test system.

Figure 4(b) shows the output waveform (red curve) of this spherical pulse compressor prototype during the high power test. According to the power meter, a peak power gain of 5.74 was achieved. In the accelerator filling time 0.372 µs, the average power gain was 3.77. The test results indicated that this prototype matches the design well.

CONCLUSION

The present study measured and tested a new type of C-band compact spherical RF pulse compressor for SXFEL energy upgrading. The single spherical resonant cavity stored RF power with two degenerated $TE_{1,1,3}$ modes. With this design, the pulse compressor becomes much more compact. Hence the space of the RF system can be saved significantly. Test results agreed with the design well. The peak RF power was multiplied by 5.74 times, and the average power gain was 3.77.

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