ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF033

RF STUDY AND COLD TEST OF AN S-BAND SPHERICAL CAVITY PULSE COMPRESSOR*

J. Lei[1, †], X. He, M. Hou, X. P. Li, G. X. Pei, H. Wang, J. B. Zhao, G. Shu, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Chinese Academy of Science, 100049 Beijing, China
[1]also at University of Chinese Academy of Science, 100049 Beijing, China

Abstract

An S-band (2856 MHz) spherical cavity pulse compressor has been designed, fabricated and tested in the Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS). The pulse compressor consists of a special 3 dB coupler and only one spherical energy storage cavity, two TE_{114} modes are chosen to oscillate in which for fairly high unload Q factor. The prototype was made of aluminum for studying the performance of the pulse compressor and checking the validity of the simulations. The cold test results of the aluminum cavity are also presented. The copper coating on the whole internal surface of the aluminum spherical cavity is in progress and the test results will also be presented in the future.

INTRODUCTION

The pulse compressor is one of the essential microwave devices in the normal temperature electronic linear accelerators. It can enhance the accelerating gradient of an accelerator by improving the peak power of the pulse from the klystron at the cost of a relatively shorter pulse.

The Stanford Linear Energy Doubler (SLED)-type pulse compressor was first proposed in 1974 [1] and was most widely used all over the word because of its simplicity of the structure. However, the fast exponentially decaying output pulse was not able to meet the need of the multi-bunch application. Thus, the flat output pulse then became one of the main developing tendencies. The development of the Phase Modulation- Amplitude Modulation (PM-AM) technology [2] remedied the disadvantage of the SLED-type pulse compressor. The simple compact structure as well as the high unloaded *Q* factor was another main developing tendency. Hereafter the pulse compressors with a single storage cavity such as the Barrel Open Cavity (BOC) type [3, 4] and the spherical cavity pulse compressor type [5, 6] were developed.

In the paper, an S-band spherical energy storage cavity pulse compressor has been designed, simulated and cold tested in IHEP. The whole research aims at checking the reasonability of the design and simulation as well as gaining experience in the fields of the Radio Frequency (RF) pulse compressor design.

MAIN PARAMETERS

The spherical energy storage cavity pulse compressor belongs to the SLED-type. It is composed of a 3 dB coupler (circular polarizer) and only one spherical cavity. For the high unloaded *Q* factor, two TE_{114} modes are chosen to be the operating modes. Compared to the traditional SLED-type, the spherical cavity pulse compressor has got a more compact structure with the same unloaded *Q* factor, or a higher unloaded *Q* factor with the same volume.

The length of the input pulse from the klystron is 4 μs and is compressed to 0.83 μs by the pulse compressor. The unloaded *Q* factor of the spherical cavity is proportional to the radius of the cavity [5], which is $Q_0=a/\sigma$ (where a is the radius of the cavity and σ is the skin depth). For TE_{114} modes in vacuum, the relationship between the radius and the resonant frequency can be expressed as $a=u_{14}c/2\pi f$, where u_{14} is the fourth root of the spherical Bessel function $\hat{J}_1(\mathrm{x})$ [7]. The main specifications of the spherical cavity pulse compressor is shown in Table1. The coupling coefficient β is designed to 9 to maximize the energy multiplication factor *M*.

Table 1: Main Specifications of the S-band Spherical Cavity Pulse Compressor

Parameter	Design value
Resonant frequency (GHz)	2856
Operating mode	TE_{114}
Unloaded *Q*	~190,000
Coupling coefficient β	9
RF input pulse length (μs)	4
RF compressed pulse length (μs)	0.83
Energy multiplication factor *M*	1.75
Peak power gain	5.75
Effective power gain	3.49

SIMULATED OF THE 3 DB COUPLER

The 3 dB coupler outputs two TE_{11} modes in cylindrical waveguide port, which has the equal amplitude but 90º phase difference. Thus, the 3 dB coupler is also a circular polarizer. The 3 dB coupler is designed by taking reference [8] as an example. The simulated electrical field distribution as well as the S-parameters from the Computer Simulation Technology (CST) software is shown in Fig. 1. The S(N:P, M:Q) means the Q mode inputs from Port M while the P mode outputs from Port N. Because in Port 1 there is only one mode TE_{10} while in Port 3 there are two polarized degenerated mode TE_{11}, P mode can be 1 or 2.

* Work supported by National Natural Science Foundation of China (11505199)
† email address: leijie@ihep.ac.cn

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF033

The simulated S parameters show that the reflection and isolation are both below -50 dB and the phase difference is 89.79° at 2.856 GHz.

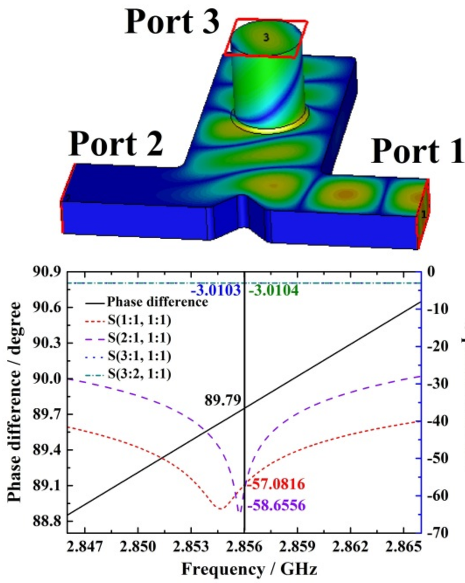

Figure 1: The simulated electrical field distribution and the S parameters of the pulse compressor.

SIMULATION OF THE SPHERICAL CAVITY PULSE COMPRESSOR

After the simulation of the 3 dB coupler, a spherical cavity is connected to simulate the microwave performance of the whole pulse compressor. The 3D model and the electrical filed distribution of the pulse compressor is shown in Fig. 2, in which the vacuum model in CST is used. We can see that the field distribution meet the TE_{114} mode.

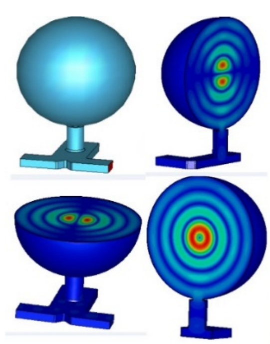

Figure 2: The 3D vacuum model of the whole pulse compressor and the electrical field distribution of TE_{114} mode.

The simulated S21 of the pulse compressor by CST Frequency Domain Solver (FDS) is shown in Fig. 3 with the background material set to be the Oxygen-free High-conductivity Copper (OFHC). The minimum value of S21 is 0.7997, from which the coupling coefficient β is calculated to be about 9. And based on the simulated half-maximum frequency bandwidth, Q_0 can be calculated to be about 182,000.

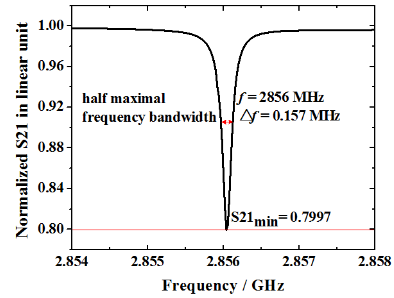

Figure 3: The simulated S21 of the pulse compressor in CST FDS.

However, limited to the project budget as well as the large volume of the spherical cavity which results in difficult of obtaining the original OFHC material. The actual prototype uses the material of aluminium for the spherical cavity and OFHC for the 3 dB coupler. Thence new simulations need to be carried out for material combination of the aluminium and OFHC. The simulated result of Q_0 is shown in Fig. 4 which is about 145,000.

H-Field data: 2D/3D Results\Fields\h-field [1], f = 2.85564

Material/Solid	Conductivity	Mu	Loss/W	Loss/%	Q
Cond. Enclosure	5.8000e+007	1	0.0000e+000	0	
material1	5.8000e+007	1	1.2495e-003	0.673	2.1578e+007
material2	3.7200e+007	1	1.8438e-001	99.3	1.4624e+005
Sum			1.8563e-001		1.4525e+005

Figure 4: The simulated result of Q_0 using the combined material of aluminium and OFHC.

COLD TEST OF THE PROTOTYPE

A prototype of the spherical cavity pulse compressor is fabricated and tested using the Agilent 8720ES Vector Network Analyser (VNA). The resonant frequency f, coupling coefficient β and the half-maximum frequency bandwidth Δf are tested. Then the Q_0 can be calculated by the formula $Q_0 = (1+\beta)f/\Delta f$. The photo of the prototype and the S21 curve from VNA are shown on the top and bottom of Fig. 5 respectively.

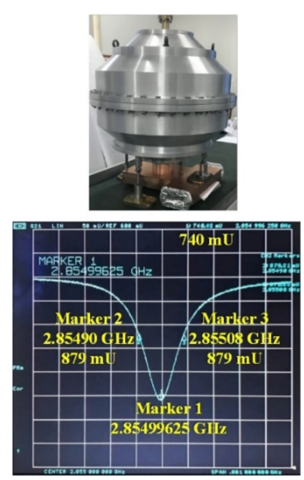

Figure 5: Photo of the fabricated prototype and the tested S21 curve from VNA.

We can get $f \approx 2854.996$ MHz, $\Delta f \approx 0.176$ MHz from Fig. 5. The coupling coefficient is about 6.72 read from

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF033

the VNA. Thus the Q_0 is about 125,000 (~86% of the simulated value).

The pulse compression performance is also tested by connecting the RF signal generator, arbitrary waveform generator, the Phase Shift Key (PSK), the pulse compressor and the peak power meter together. The waveform of the final output pulse is shown in Fig. 6. The peak and average power gain are about 597 % and 326 % respectively calculated from the output pulse curve.

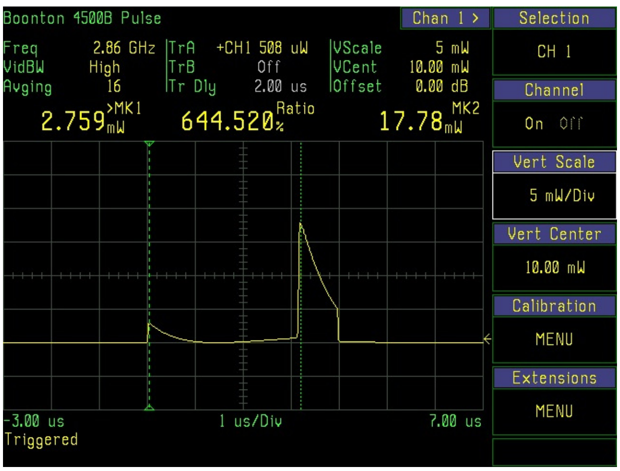

Figure 6: The output pulse waveform of the spherical cavity pulse compressor.

CONCLUSION

A prototype of an S-band spherical cavity pulse compressor has been designed, fabricated and cold tested in IHEP. It consists of an OFHC 3 dB coupler and an aluminium spherical cavity. The consistency of the simulated and tested results proves the design procedure to be rational. The pulse compression performance in both simulation and test are satisfactory. The fabrication of the pure OFHC material spherical cavity pulse compressor as well as the high power test will be carried out in the future.

REFERENCES

[1] Z. D. Farkas, H. A. Hogg, G. A. Loew, and P. B. Wilson, "SLED: a method of doubling SLAC's energy", in *Proc. 4th Int. Conf. on High Energy Accelerators*, California, USA, May. 1974, pp. 597-604.

[2] T. Shintake, and N. Akasaka, "A new RF pulse-compressor using multi-cell coupled-cavity system", in *Proc. 5th European Particle Accelerator Conf. (EPAC'96)*, Barcelona, Spain, Jun. 1996, paper WEP060L, pp. 2146-2148.

[3] I. V. Syrachev, "The progress of X-band 'open' cavity RF pulse compression system", in *Proc. 4th European Particle Accelerator Conf. (EPAC'94)*, London, England, Jun. 1994, pp. 375-379, ***doi:10.1.1.524.1846***

[4] R. Zennaro *et al.*, "C-band RF pulse compressor for SWISSFEL", in *Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May. 2013, paper WEPFI059, pp. 2827-2829.

[5] J. W. Wang, S. G. Tantawi, and X. Chen, "Super-compact SLED system used in the LCLS diagnostic system", in *Proc. 27th Linear Accelerator Conf. (LINAC'14)*, Geneva, Switzerland, Sep. 2014, paper THPP125, pp. 1151-1154.

[6] J. W. Wang *et al.*, "R&D for a super compact SLED system at SLAC", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May. 2016, paper MOOCA01, pp. 39-41.

[7] R. F. Harrington, "Time-harmonic electromagnetic field", McGraw-Hill Book Company, 1961.

[8] M. Franzi, J. W. Wang, V. Dolgashev, and S. G. Tantawi, "Compact RF polarizer and its application to pulse compression system", *Phy. Rev. Accelerators and Beams*, vol. 19, p. 062002, 2014, ***doi:10.1103/PhysRevAccelBeams.19.062002***