DESIGN, FABRICATE AND COLD TEST OF A C-BAND BARREL OPEN CAVITY PULSE COMPRESSOR*

G. Shu#, F. Zhao, N. Song, J. Zhang, M. Hou, S. Pei, X. Zhang, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Chinese Academy of Science, Beijing, China

Abstract

A prototype of C-band (5712 MHz) pulse compressor which utilizes barrel open type cavity (BOC) is designed, fabricated and cold tested by the Institute of High Energy Physics, Beijing. For BOC, one cavity is sufficient to realize the pulse compression. In our case, the "whispering gallery" mode $TM_{6,1,1}$, which has an extremely high unload Q, is chosen as the resonant mode. The basic dimensions of the BOC are obtained in the RF design with the help of simulation codes HFSS and CST. The time domain analysis is carried out to calculate the BOC transient output response. Machining and brazing processes are designed based upon our existing processing capabilities. The cold test results will also be presented in this paper.

INTRODUCTION

As is well known, a C-band accelerating structure has a higher gradient than a traditional S-band tube. Comparing to the X-band system, the C-band unit has more available commercial components and requires less complicated fabrication technology. Therefore, the C-band technology plays a significant role in the normal temperature electronic linear accelerator.

The pulse compressor which is widely used in the linear accelerators is of importance to increase the power efficiency of the klystron RF power and the accelerating gradient. Unlike the traditional SLED type pulse compressor, the BOC is composed of a single barrel open cavity and a matching waveguide [1,2]. The travelling wave whispering gallery mode is chosen to oscillate in the barrel cavity. Due to the low power loss on the inner surface, BOC has an extremely high unload Q. A prototype has been manufactured by IHEP to explore the RF properties of the BOC and to gain the experience in the braze processing.

RF DESIGN

The performance of a pulse compressor depends on the resonant frequency, the unload Q and the coupling coefficient. The main specifications the BOC are summarized in Table 1.

The unload Q of the BOC is proportional to the cavity size. It can be defined as r/σ, where r is the cavity radius and σ is the skin depth. Considering the performance and fabrication cost of the prototype, the $TM_{6,1,1}$ mode with an unload Q factor of 95,000 is finally chosen as the resonant mode. The length of the RF pulse coming from the klystron is 3 μs. The compressed pulse length is 0.33 μs, which is determined by the accelerating tube filling time. The coupling factor of 4.5 results in the maximum power gain.

The cavity is magnetically coupled with the input waveguide through 24 identical coupling slots. The distance of adjacent slots is chosen as λ_g /4 to suppress the backward wave to the klystron. Phase velocities of the travelling waves in the waveguide and cavity are matched by adjusting the width of the waveguide. Slots dimensions are optimized so as to obtain the best coupling coefficient. The detailed dimensions of the BOC are determined by the 3-D codes software HFSS [3] and CST Microwave Studio (MWS) [4], as shown in Figure 1.

Table 1: Main specifications of the C-band barrel open cavity pulse compressor.

Parameters	Values	Units
Frequency	5712	MHz
Resonant mode	$TM_{6,1,1}$	
Coupling coefficient	4.5	
Unload Q factor	~95,000	
Insert loss at detuned condition	0.1	dB
VSWR at f_0	1.05	
RF input pulse length	3	μs
RF output pulse length	0.33	μs
Max. input power	50	MW
Repeat rate	60	Hz
Peak power gain (calc.)	610%	
Average power gain (calc.)	420%	

#shug@ihep.ac.cn

Copyright © 2017 CC-BY-3.0 and by the respective authors

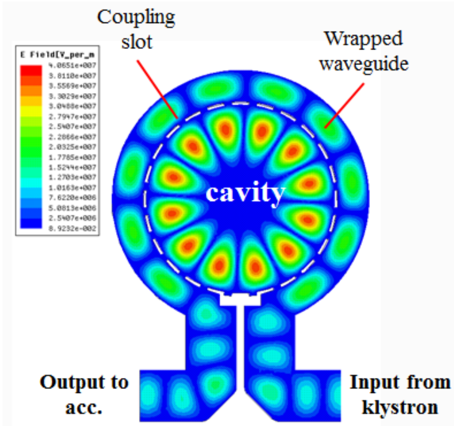

Figure 1: Electric field distribution on a median plane of BOC pulse compressor simulated by HFSS.

TRANSIENT RESPONSE ANALYSIS

Transient response analysis is done by CST MWS transient solver to numerically simulate the BOC output in time domain. Only hexahedron mesh is available, which makes the resonant frequency and the coupling coefficient a bit different from frequency domain solver results. The excitation signal with a pulse width of 3 µs is imported into MWS, as shown in Figure 2(a). The phase of the input signal reverses 180° at 2.67 µs. Figure 2(b) illustrates the BOC response in time domain. The output pulse waveform is consistent with the theoretical waveform.

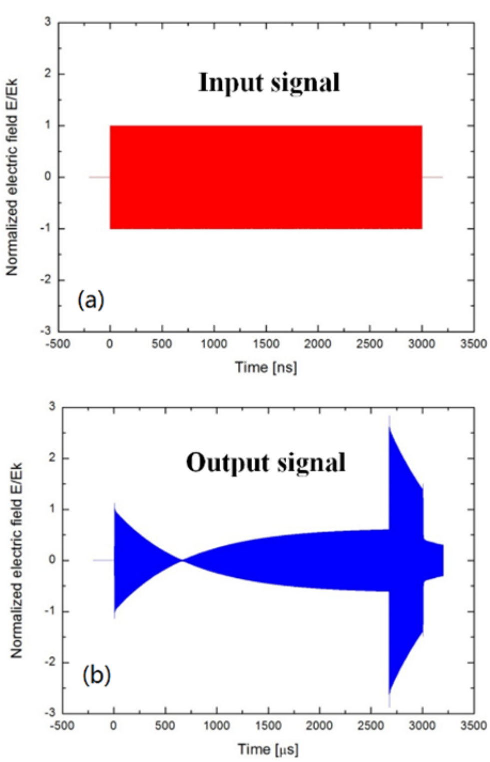

Figure 2: (a) and (b) correspond to the input and the output signals of BOC simulated by MWS transient solver.

FABRICATION AND TUNING

A BOC prototype is fabricated following the numerical simulations. The main material used to build the cavity is oxygen free copper. Vacuum flanges, parts of the ports and cooling channels are made of stainless steel.

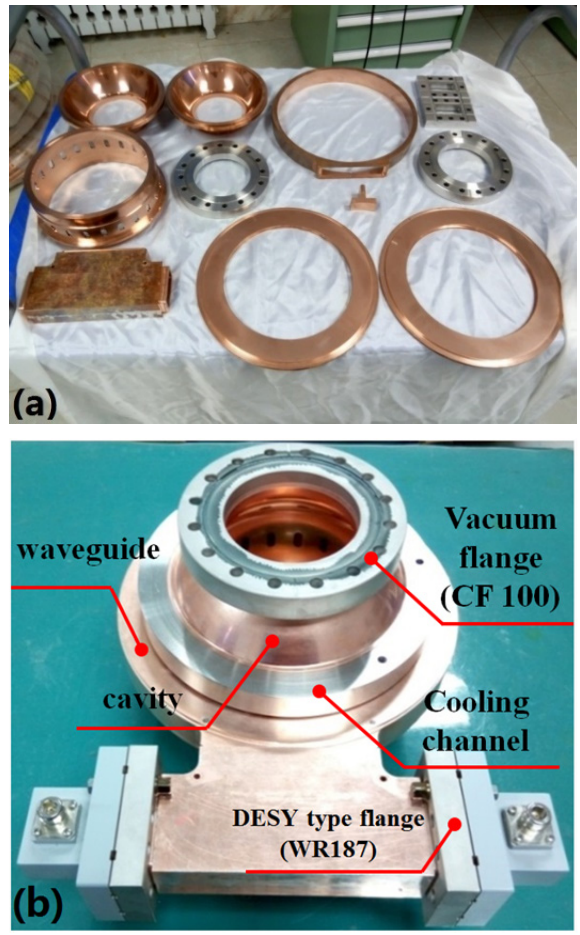

Figure 3: (a) and (b) indicate the BOC before and after brazing, respectively.

The structure is realized by mechanical machining with a numerically controlled lathe. The obtained precision is below 10 µm and the surface roughness is not worse than 0.4 µm. In order to suppress the cavity deformation during mechanical tuning procedures, the cavity and waveguide components are machining separately. Figure 3 shows the BOC before and after brazing process.

The cavity is roughly tuned from 5719.91 MHz to 5713.98 MHz by trimming the tuning rings twice before brazing, as shown in Figure 4. The tuning sensitivity is ~2.96 MHz/mm. The cavity has a slight deformation during the brazing process. After brazing, the cavity resonant frequency increases by ~0.6 MHz. The BOC will be finally coarse tuned to 5712±0.5 MHz by a third trimming in next days. The frequency will be precisely tuned to 5712 MHz by cooling water temperature in high power operation state. According to theoretical calculation the tuning sensitivity of the water is ~98 KHz/℃.

ISBN 978-3-95450-182-3

Copyright © 2017 CC-BY-3.0 and by the respective authors

After the brazing process, a vacuum leak test is carried out using a copper gasket and a helium leak detector. The measured leak rate is about 10^{-9} mbar·L/s.

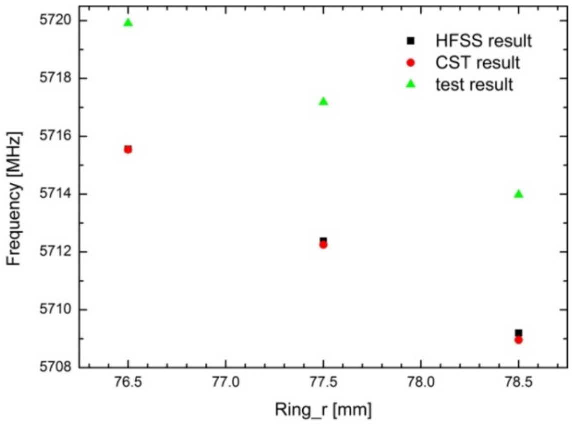

Figure 4: Coarse tuning of the cavity.

COLD TEST

After brazing, the low power test is implemented. The vector network analyser (Agilent 8720ES) is used to measure the resonant frequency, unload Q and coupling factor. The cavity impendence Z=R+jX is indicated on S21 smith chart, as shown in Figure 5. The resonant frequency f_0 of the BOC is 5714.6 MHz. The coupling factor is 4.7, which is achieved by $Z(f_0)/50\Omega$. The unload Q of the BOC is defined as $Q_0=f_0/\Delta f$, where Δf is the frequency internal of $R=\pm X$. The measured value for the unload Q is 87700, which is about 92% of the theoretical value.

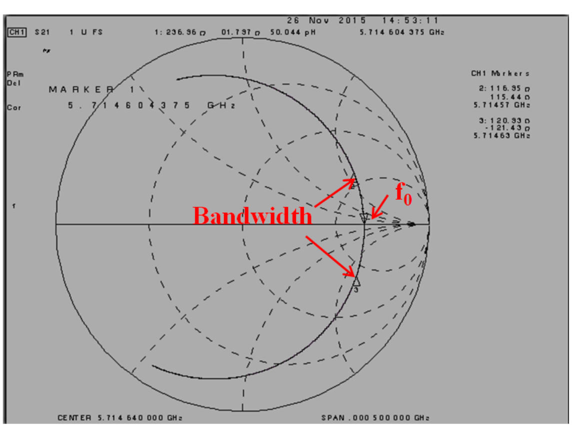

Figure 5: Smith chart of S21.

The phase reversal of the input pulse coming from the RF signal generator is realized by an IQ modulator (Pulsar IMOH-01-458). The control level is generated by an arbitrary waveform generator (Agilent 33250A). Then the modulated pulse is fed into the BOC cavities. The peak power meter (BOONTON 4500B) is used to monitor the output waveform.

Figure 6 shows the output RF pulse waveform. The peak power gain achieved in the cold test is ~560%. The average power gain which is defined as the RF power integrated over the filling time of the accelerating structure is ~380%.

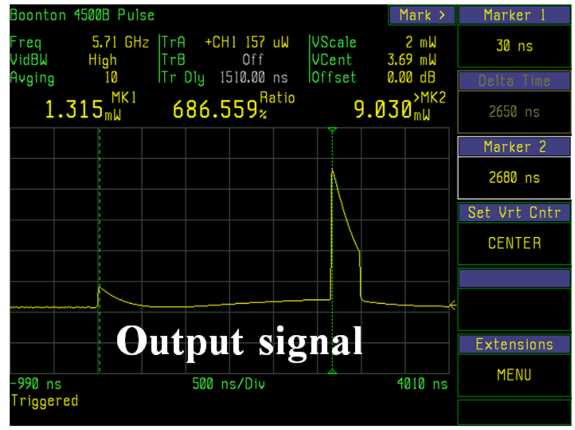

Figure 6: Output RF pulse waveform of BOC in the low power test.

CONCLUSIONS

This paper describes the studies and the activities carried out by IHEP, for the development of the C band BOC pulse compressor. In this paper, we report on the RF design, fabricating scheme and preliminary measurements of its RF properties. An average power gain of 380% is achieved in the cold test. After the third coarse tuning, a high power test will been performed to confirm the stability and reliability of this BOC.

REFERENCES

[1] Brown P, Syratchev I., 3 GHz Barrel Open Cavity (BOC) RF pulse compressor for CTF3[C]// Microwave Symposium Digest, 2004 *IEEE MTT-S International*. *IEEE*, 2004:1009-1012 Vol.2.

[2] Zennaro R, Bopp M, Citterio A, *et al.*, C-BAND RF PULSE COMPRESSOR FOR SWISSFEL[C], in *Proc. IPAC13*, Shanghai, China, 2013, WEPFI059.

[3] http://www.ansoft.com/products/hf/hfss/

[4] http://www.cst.com/Products/CSTMWS

Copyright © 2017 CC-BY-3.0 and by the respective authors