Multisectional RF compressor for the mobile electron accelerator

G.O. Buyanov[1], **A.P. Klachkov and A.G. Ponomarenko**
National Research Nuclear University MEPhI, 115409, Russia, Moscow, Kashirskoe highway 31

E-mail: frontlines.07@gmail.com

Abstract. Set out a design of the RF compression system, based on the Blumlein line principle. This particular design is based on TE01 mode in rectangular waveguide. Presented solution for TE01 excitation system with effective suppression of other modes. Presented designs 2-sectional and 6-sectional versions of compressor. Set out calculated Q factors, expected output powers and other parameters for these designs.

1. Introduction

RF compression systems is important part of modern high power pulsed systems. Particle accelerators is one of the areas where high RF pulsed power needed the most. We consider such systems will become important part of the future compact linear electron accelerators with high field gradient. NRNU MEPhI team worked over the RF compression system based on Blumlein line principle (BLP) [1,2,3,4].

Significant disadvantage of earlier designs [3,4] was limited frequency range. For the S-band their compression multiplier was about 100, but in X-band it goes down to 20 due to Q factor change. By the compression multiplier we mean relation of resonator τ to length of output pulse.

To increase Q factor and stored energy could be used larger waveguide with higher mode excitation. Our specific design is based on TE_{01} mode. In table 1 presented comparison of designs based on TE_{01} and TE_{10}. So for X-band (8.568 GHz to be accurate) TE_{01} based design have 3 times larger stored energy and about 4 times higher output power.

Table 1. Comparison of TE_{01} and TE_{10} based designs.

	TE_{10} based 28.5×12.6 mm	TE_{01} based 72×28.5 mm
Output pulse length, ns	10	
Input pulse length, μs	0.2	0.60
Q	10700	32000
Compression multiplier	19.5	60

[1] To whom any correspondence should be addressed.

P_{out}, MW	16.6	70
P_{inp}, MW	3.3	1.2

2. BLP based TE_{01} compressor

One of the most important parts of BLP based compressor is the output coupler. It should efficiently pass or not pass the power depending on the phase of incoming waves. It also should be optimized to withstand full output power of the compressor. 3D model of the coupler design shows on Fig. 1.

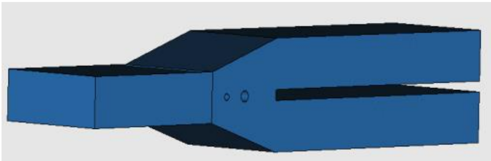
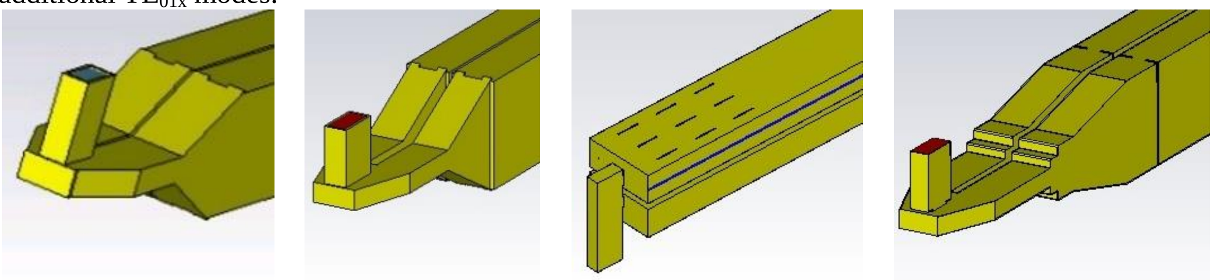


Fig. 1. Output coupler design.

Second one important part of the BLP based compressor is the input coupler. It should include mode converter from TE_{10} of power source to TE_{01}, insure 180° phase shift and suppress TE_{n0} modes. We assume to use 28.5×12.6 mm (WR-112) or 23×10 mm (WR-90) input waveguide. For the main body of the compressor was supposed to use 72×34 mm (WR-284) waveguide, but its height caused the higher and hardly suppressible modes excitation. To overcome this effect we assume to use nonstandard waveguide 72×28.5 mm. This exact size was chosen to simplify coupling with 28.5×12.6 mm input and output waveguides. On the Fig. 2 shows the input coupler designs we worked on. On Fig. 2 a,b shown smooth transition from 28.5×12.6 mm and 23×10 mm respectively. Fig. 2 c shows direct excitation with TE_{n0} suppression filter. The optimal design we found in combining stepwise and smooth transition (Fig. 2 d).

Overall view of the compressor is shown on Fig. 3. Calculated electrical field distribution is shown on Fig.4. $E_y(z)$ distribution is slightly (about 2%) modulated due to hardly suppressible excitation of additional TE_{01x} modes.



a b c d

Fig. 2. Input coupler designs.

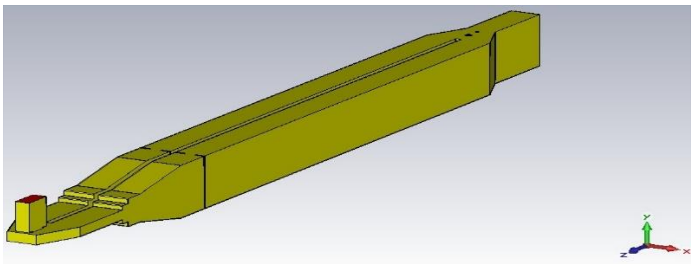


Fig. 3. 3D model of BLP compressor on 72×28.5 mm waveguides.

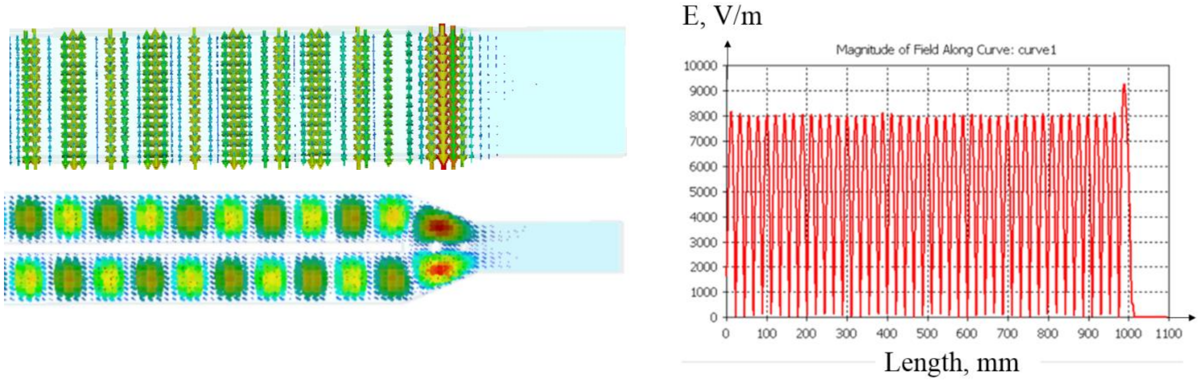


Fig. 4. Electrical field distribution in compressor.

3. 2-sectional TE_{01} compressor

To further increase output power we suppose to use one more advantage of BLP based compressor, ability to combine several fully synchronized sections. To make it work we need joint phase shifting module, based on discharge gap for example. On the Fig. 5 a shown design of such compressor for the 2-sectional case. Excitation of both section should be synchronized. One of the possible ways to do so is using single generator and 3dB coupler (Fig. 5 b).

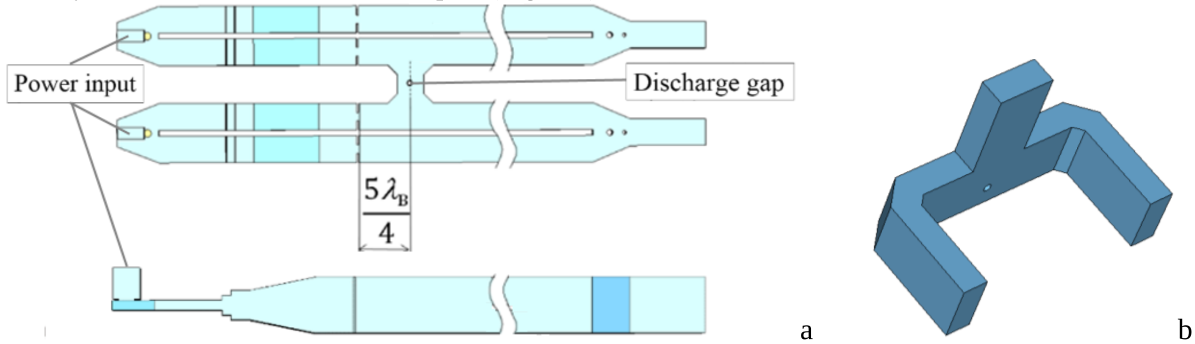


Fig. 5. 2-sectional compressor design and input 3dB coupler

3.1. Phase shifting module.

Joint phase shifting module is the area with maximum EM field in 2-sectional compressor. It's design and field distribution shown in fig. 6. Electrical field in the discharge gap area about 1.4 times higher than regular field in compressor waveguides. That is unavoidable, due to stacking power flows from 2 generators with adequate field increase.

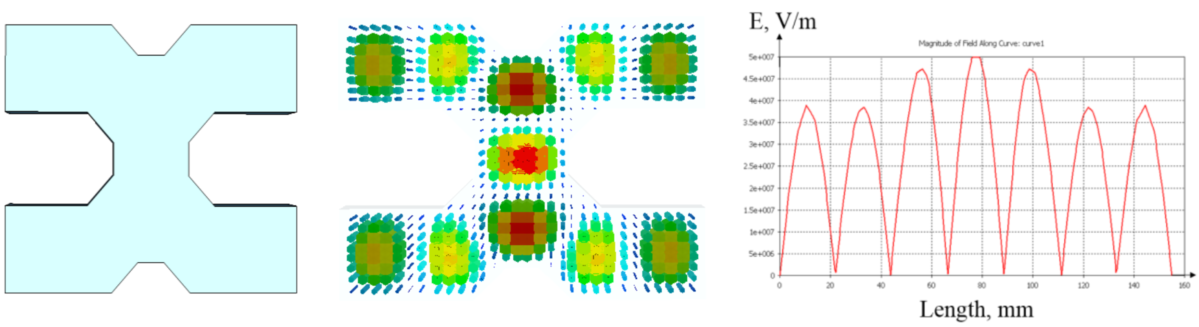


Fig. 6. Joint phase shifting module and electrical field distribution in it.

RF phase shifting is the one of the most important events in BLP based compressor. Fast (about 1ns) and lossless phase shift insures good output waveform and overall compressor operation. The good phase shifting criteria is pretty oblivious:

Journal of Physics: Conference Series **747** (2016) 012086 doi:10.1088/1742-6596/747/1/012086

$$|\varphi_2 - \varphi_1| = 180°$$
$$S_{11} \sim 1$$

φ_1 – wave phase before the shift, φ_2 – wave phase after the shift, S_{11} – scattering parameter (reflection coefficient).

The gap discharge itself was not in the focus of this work, therefore we analyze 2 states – "before" and "after" the phase shifting. The plasma column of discharge was represented by conductive cylinder (fig.7). Simulation results presented in the table 2. In the both cases efficient BLP based compressor operation is achievable.

Fig.7. Joint phase shifting module with conductive cylinder for plasma column imitation.

Model №	S_{11}	φ_1	φ_2	R_{pc},mm
1	0.9998	6.9°	186.4°	10.7
2	0.9834	207.2°	27.7°	2.6

4. 6-sectional TE_{01} compressor

As the way to further increase output power of the BLP based compressor we considering use of 6-sectional design. The first design we tried was based on our earlier works [3, 5, 6] with TE_{10} compressors (fig 8, a). The joint module itself was good, but the H-bend of the waveguide caused serious distortion in TE_{01}. We don't find the efficient solution for this distortion problem, but other design was offered (fig 8,b). This joint module design could be called "vortex" design because it based on the vortex electrical field. The main idea is that there is no discharge gap and phase shift should be caused by the plasma ring. That is an advantage and disadvantage in the same time. Such design could withstand extremely strong electric field, but creation the required plasma ring is difficult. One more difficulty is field line distortion in output waveguides (fig. 9, right).

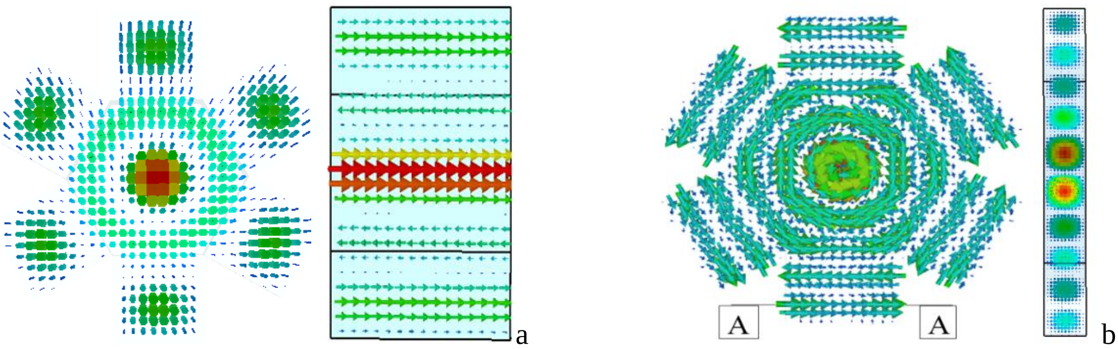


Fig. 8 Electrical field distributions for TE_{01} 6-sectional compressor joint phase shifting modules.

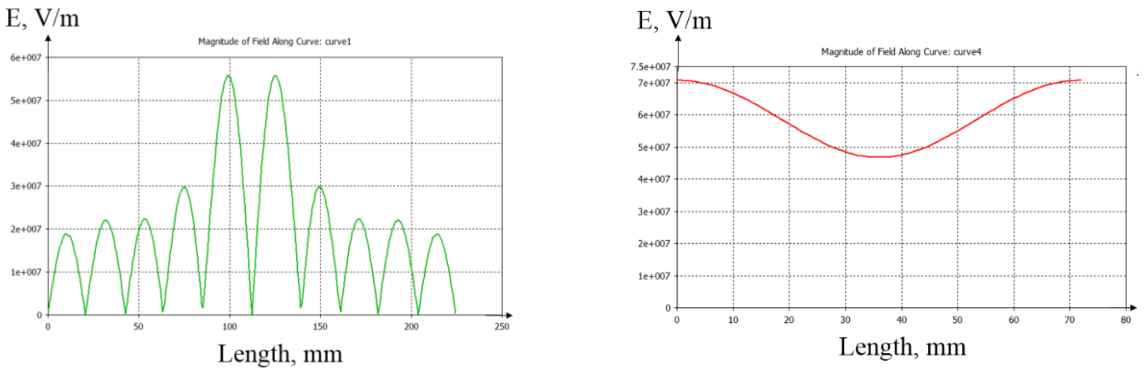


Fig. 9. E_φ distribution in “vortex” (on the left) and in A-A section of the waveguide.

4.1. Dielectric parts in 6-sectional compressor.

To eliminate the field line distortion and make a surface for electrical discharge we consider partial dielectric filling of the joint module. The possible filling scheme shown in fig. 10. The calculated field distribution shown in fig. 11. Field distortion in the waveguides was reduced from 35% to less than 5% of amplitude. Fig. 12 shows electric field distribution inside of dielectric filler in the middle of joint module. The exact border of the dielectric filler should be determined by the surface discharge condition and can be moved into area of more or less intense field. The overall construction of X-band 6-sectional compressor design presented in fig.13. The waveguides length is 1m for a 10 ns output pulse.

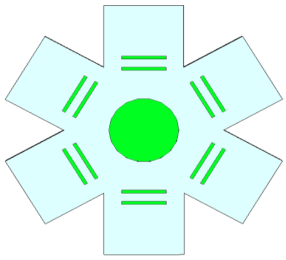
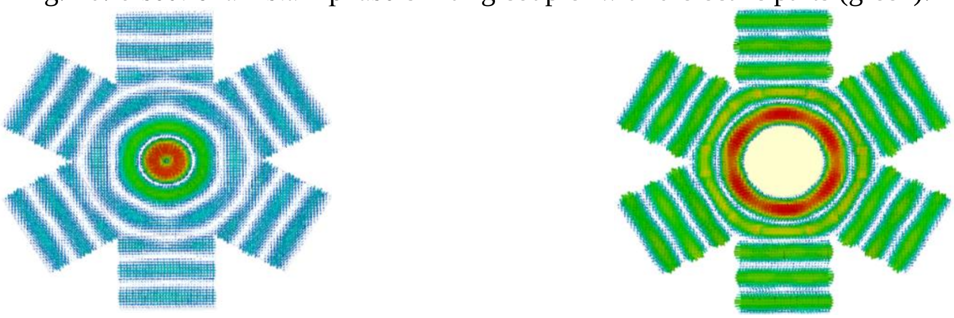


Fig. 10. 6-sectional “star” phase-shifting coupler with dielectric parts (green).



before phase shift after phase shift

Fig. 11. Electrical field distribution for “vortex” based 6-sectional phase shifting module.

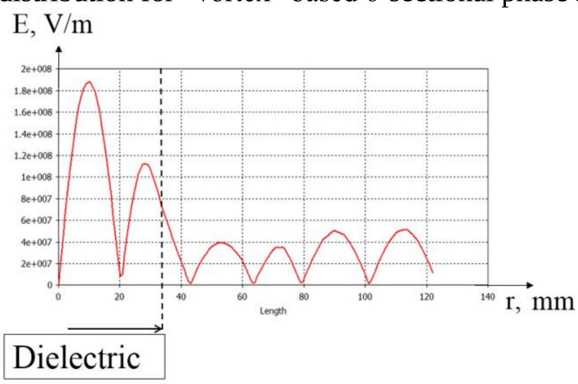


Fig. 12. Radial E_φ distribution in “vortex” with dielectric parts installed.

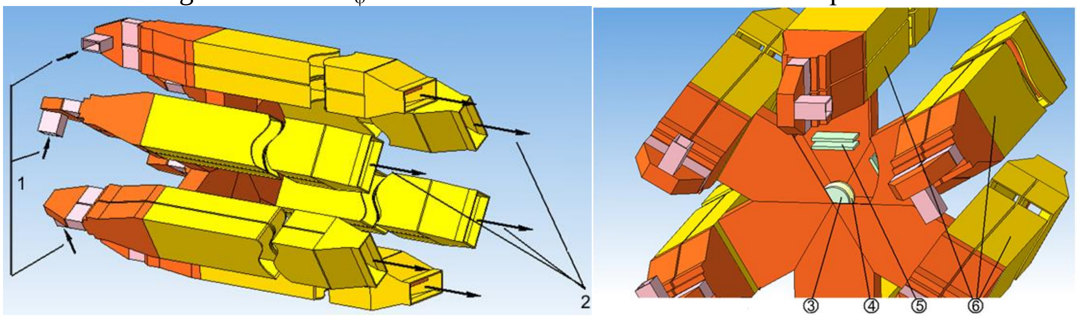


Fig. 13. 6-sectional BLP based compressor. 1- input waveguides, 2 – TE_{01} power outputs, 3 central dielectric filler, 4 – surface discharge area, 5- dielectric plates for distortion suppression, 6 – BLP sections.

5. Conclusion

We expect the output power of the single section of BLP X-band TE_{01} compressor will up to 70 MW pulsed. For the 6-section design, the total output power will about 400 MW for a 10 ns. Most important characteristics for single, dual and 6-section designs are combined in table 2. We believe that high specs of such compressor will allow to make a future generation compact particle accelerators. Authors are grateful to A.A. Osipov for a constructive criticism.

Table 2. X-band TE_{01} compressor parameters.

	single	**2-sectional**	**6-sectional**
Q	32000	21500	18000
Compression multiplier	60	40	30
Energy capacity, J	0.75	1.50	4.50

References

[1] Ponomarenko A G Microwave-pulse time compression device *Patent RU № 2293404* since 10.02. 2007.
[2] Ponomarenko A G 2007 *Moshchnaya impulsnaya tekhnika*. *Elementy skhem i istochniki pitaniya* (M.: MEPhI 97-111
[3] Osipov A A and Ponomarenko A G Razrabotka kompressora energii impulsa svch-pitaniya mobilnogo lineynogo uskoritelya elektronov (LUE) *Nuclear Physics and Engineering* **4** 28-32
[4] Osipov A A and Ponomarenko A G Device for Time Compression of Microwave Energy Pulses *Patent RU № 2472260* since 10.01. 2013
[5] Bogdanovich B Y, Kalyuzhny V Y, Masunov E S, Nesterovich A V, Ponomarenko A G and Senyukov V A 2009 Concept of mobile source of narrow gamma radiation *Problems of atomic science and technology* **2** 73-80
[6] Osipov A. A and Ponomarenko A G 2010 Modelirovanie perehodnogo protsessa vyvoda energii iz svch kompressora radioimpulsov na osnove DFL *Nuclear Physics and Engineering* **1** 438-449