PHASE MODULATOR PROGRAMMING TO GET FLAT PULSES WITH DESIRED LENGTH AND POWER FROM THE CTF3 PULSE COMPRESSORS

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Abstract

The pulse compressor is located after the klystron to increase the power peak by storing the energy at the beginning and releasing it near the end of klystron output pulse. In the CTF3 [1] pulse compressors a doubling of the peak power is achieved according to our needs and the machine parameters. The magnitude of peak power, pulse length and flatness can be controlled by using a phase modulator for the input signal of klystrons. A C++ code is written to simulate the pulse compressor behaviour according to the klystron output pulse power. By manually changing the related parameters in the code for the best match, the quality factor and the filling time of pulse compressor cavities can be determined. This code also calculates and sends the suitable phase to the phase modulator according to the klystron output pulse power and the desired pulse length and peak power.

INTRODUCTION

The available klystrons in CTF3 provide us about 30MW peak power during about 6μs. The maximum beam pulse length is about 1.5μs and the filling time of each accelerating section is about 0.1μs. This encourages us to increase the peak power by shortening its length. It is possible to do so by pulse compressors that store the energy in the beginning of pulse and release it near the end of pulse. Two types of pulse compressors are used in CTF3; LIPS and BOC [2] types. A phase modulator is used for each RF input of the klystrons to control the final pulse shape as described in the phase modulation section. For us the details of these two types of pulse compressors are not important and the behaviour of both is the same as we look at them as a black box. We can use one equivalent circuit for both of them as suggested by Fiebig [3] (See Fig. 1).
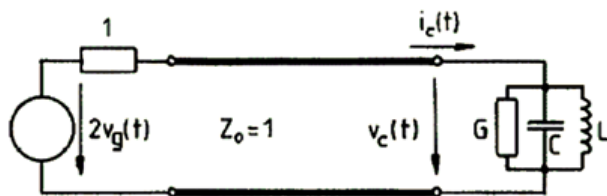

Figure 1: The equivalent circuit of pulse compressor

In fig. 1, the left part represents the generator (klystron) and the right part represents the pulse compressor as a resonator. They connect to each other by a transmission line that its characteristic impedance is normalized to 1.

The reflected wave in the transmission line is directed to the acceleration section by a 3db hybrid coupler. The relation between the generator (klystron) and the pulse compressor equivalent voltage was shown [3] in complex form in the equation 1 where V_g and V_c are the generator and pulse compressor equivalent complex voltage, respectively and $\alpha=2\beta/(1+\beta)$ where β is the coupling coefficient between the pulse compressor and the transmission line and τ is the filling time of pulse compressor. τ is equal to $2Q_0/[(1+\beta)\omega_0]$ where Q_0 is the unloaded quality factor of pulse compressor and ω_0 is the angular resonant frequency of RF wave. In the CTF3, β is about 7 and Q_0 is about 180000 and $\omega_0/2\pi$=2.99855 GHz. Then α is about 1.7 and τ is about 2μs.

$$\alpha V_g = V_c + \tau \dot{V}_c \qquad (1)$$

In equation 1 it is assumed that the unloaded quality factor is high and V_g is constant or smoothly changing and also the resonant frequency of the pulse compressor and the frequency of RF wave are equal. In the case in which there is a small difference between these two frequencies the equation 1 should be replaced by equation 2 where $\Delta\omega=\omega_0-\omega_c$ and ω_c is the angular resonant frequency of pulse compressor. This little difference is necessary to minimize the reflected wave phase variation during the flat-top pulse as described in Refs. 2 and 3.

$$\alpha V_g = V_c(1 + i\tau\Delta\omega) + \tau \dot{V}_c \qquad (2)$$

We are interested to the reflected wave that is directed to the acceleration section that can be represented by $V_r=V_c-V_g$. These complex voltages are better represented by the corresponding measurable quantities (See eqn. 3). In this equation the complex voltages is represented by the power and phase. P_g is the output power of the klystron and it is known and mostly it has a rectangular form. Φ_g is determined by the phase modulator that was located at the place of RF input of each klystron. In the phase modulation section it will be showed how to calculate suitable Φ_g to reach a flat pulse with desired length and power for P_r. The variation in Φ_r during the flat-top pulse can be minimized by choosing a suitable $\Delta\omega$.

$$V_{g,c,r} = \sqrt{P_{g,c,r}}\, e^{i\phi_{g,c,r}} \qquad (3)$$

SIMULATION

Initially, a C++ code was written to simulate the pulse compressor behaviour and the result was compared to the measurement. For the simulation, the equation 2 is used for its simplicity and the equation 3 is used to calculate the complex voltages from real values. In equation 4 is showed the numerical form of equation 2 that was used in the simulation code where $V_{c,0}=0$ and $V_{c,1}=\alpha V_{g,0}\Delta t/\tau$.

$$V_{c,n+1} = V_{c,n-1} + \frac{2\Delta t}{\tau}[\alpha V_{g,n} - V_{c,n}(1+i\tau\Delta\omega)] + O(\Delta t^3) \qquad (4)$$

Figs. 2 and 3 show the result of simulation compared to the result of the measurement. It shows a good agreement between them for two different peak top lengths.
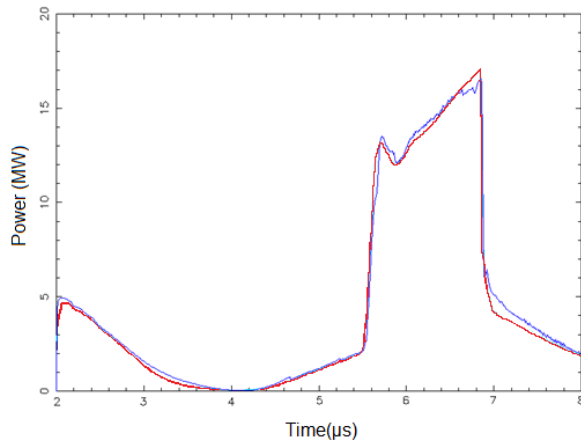

Figure 2: The output RF power from a pulse compressor in CTF3 by the simulation code (Red) and the measurement (Blue).
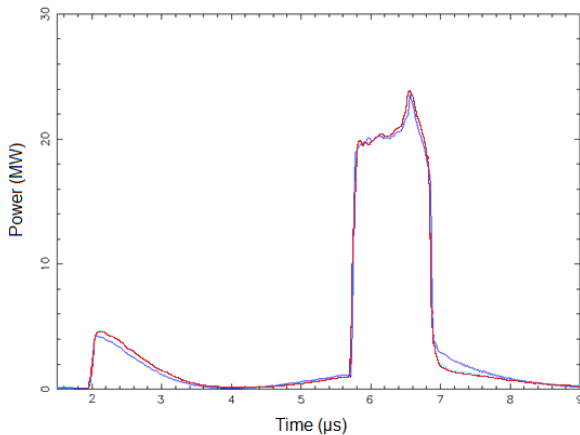

Figure 3: The output RF power from a pulse compressor in CTF3 by the simulation code (Red) and the measurement (Blue).

Also, using this code, α and τ can be determined and adjusted better. The better agreement means values for these parameters closer to the real ones, but there are other things that can introduce a mismatch. One of them is the slow response effect that it occurs when the output phase of phase modulator changes so fast that klystron cannot follow it. In this case one will see some difference between the klystron output phase and what was originally sent by the phase modulator. Another difference comes from the partial mismatch of the two cavities of LIPS type and two orthogonal modes in BOC type. From α and τ, Q_0 and β can be calculated by less accuracy because of the relation between α and β. For example if β is changed from 6 to 9, α is changed from 1.7 to 1.8.

PHASE MODULATION

It's the time to calculate the reasonable phase for the phase modulator to reach a flat-top pulse near the end of pulse compressor output. The theory is described in Refs. 2 and 3. It was showed here, how it was used in a C++ code that sends the suitable phase to reach a flat pulse with desired length and power. In the simplest case, the phase is changed by 180 degrees near the end of pulse with the result schematically shown in fig. 4. There are two jumps up in the power. The first jump is at the start of the pulse and the second is in the place that the phase was changed by 180 degrees. Afterwards, you can see an exponential decay by factor 2τ (for power).
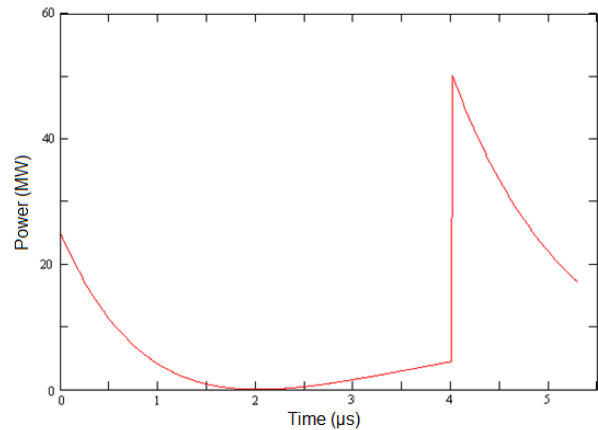

Figure 4: The output power of a pulse compressor by the phase change of 180 degrees at t=4μs.

To reach to flat-top pulse a more complicated phase function is needed. It is necessary to change the phase by less than 180 degrees and then increase it slowly to the 180 degrees to keep the power constant. Fig. 5 shows the schematic phase value that was send to the phase modulator. The klystron output pulse is supposed to be rectangular (red line), starting from point A. At point C the phase was jumped to a value less than 180 degrees by a finite slope due to slow-response effect and was increased slowly to keep the pulse flat. In the end when it reaches to 180 degrees (point E) it cannot further keep the pulse constant and it decays exponentially. It shows that there is a limit for the power can be reached depends on the desired flat-top length. The limit is when the point E is located on point F. For more desired power, we should have larger phase jump at point C that causes the point E

to be moved backward then we cannot keep the power constant until point F. At point F the klystron pulse is finished but there is still a little remaining power from the pulse compressor. The slope $-\Delta\omega$ was used as described in Refs. 2 and 3 to minimize the phase variation for the output pulse from the pulse compressors during the flat-top pulse. $-\Delta\omega$ can be found by changing the slope to minimize the power at point B.
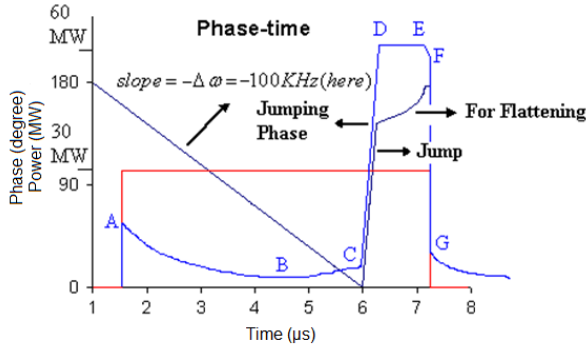

Figure 5: The phase function of the phase modulator (Blue) and the input (Red) / output (Purple) power of a pulse compressor.
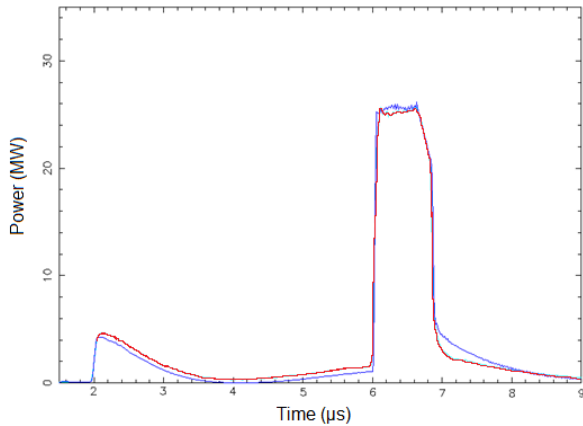

Figure 6: The amplitude of output RF power by the simulation code (Red) and the measurement (Blue).
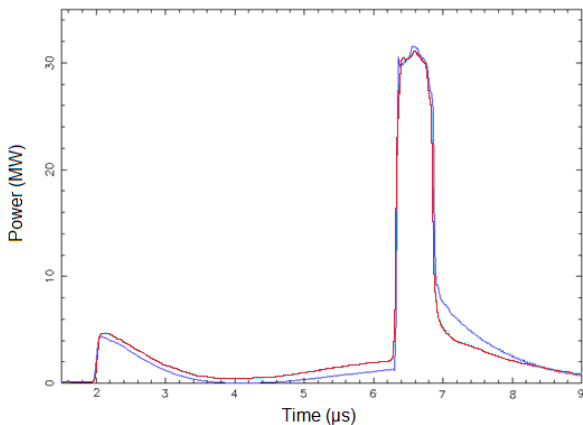

Figure 7: The amplitude of output RF power by the simulation code (Red) and the measurement (Blue).

Figs. 6 and 7 show two different examples with two different flat-top length when the suitable phase was calculated and send by the code to the phase modulator. In our case, for the maximum desired pulse length in CTF3 (around 1.5µs), twice the initial peak power can be achieved. For shorter pulse lengths higher peak power levels are achievable. In figs. 6 and 7, as you can see, we can have better end flat-top pulse by choosing less phase jump at point C (see fig. 5) but it is good enough and we can leave it like this and use an available feedback program [2] that makes small changes to the phase function while monitoring the output amplitude in order to achieve a better flat-top pulse.

CONCLUSION

Initially, the CTF3 pulse compressors are simulated with good accuracy, providing a check to the code and the theory and also allowing to find the parameters α and τ. Then one can find $-\Delta\omega$ by minimizing the power at point B in fig.5. In a second step, another code is used, with the previously found parameters, to calculate the suitable phase function for the desired flat-top pulse length and power. Such function is then sent to the phase modulator. Figs. 6 and 7 show two result of this code. Finally, an available feedback program is used to achieve a better flat-top pulse.

REFERENCES

[1] G. Geschonke, A. Ghigo (ed.) et al.: "CTF3 Design Report", CERN/PS 2002-008(RF), LNF-02/008(IR).

[2] R. Bossart, P. Brown, J. Mourier, I.V. Syratchev, L. Tanner, "High-power microwave pulse compression of klystrons by phase-modulation of high-Q storage cavities", CLIC-NOTE-592, Jun 2004.

[3] A. Fiebig and Ch. Schieblich, "A SLED type pulse compressor with rectangular pulse shape", Proc. of European Particle Conference, Nice, 1990, p.937