DEVELOPMENT OF THE X-BAND KLYSTRON MODULATOR AT KEK

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Abstract

A line type modulator with a Blumlein pulse-forming network (PFN) to drive a 75 MW pulsed klystron for the main linac of an X-band Linear Collider is under development at KEK. This Blumlein modulator yields a reasonably fast rise time and hence, an improved efficiency. A high power test of the modulator showed that an output pulse with a rise time(10%-90%) of less than 350ns can be generated for the klystron. This paper describes the design, specifications and results of the performance tests of the Blumlein modulators.

1 INTRODUCTION

The klystron pulse modulator for an X-band Linear Collider requires to produce a 454kV, 367A, 1.5µs flat-top pulse to drive a 75MW klystron[1]. The present configuration of the 0.5TeV linear collider requires more than 3200 modulators. The large number of klystrons and modulators dictate the need for a reliable and efficient system.

The power efficiency of the modulator are extremely important. The effective output power of the modulator is the power of the flat-top portion of the high voltage output pulse and hence, the pulse with a fast rise time and fall time is required. The main contributor to the pulse waveform is a pulse transformer(PT) as well as a pulse-forming network(PFN). For these designs, the transformer turns ratio plays a very important role. Using a Blumlein method allows a lower transformer turns ratio, which yields a reasonably fast rise time and hence, an improved efficiency. The efficiency target for the modulator system (wall plug to usable pulse flat-top) is 75%.

The R&D's of the Blumlein type modulator, which is based upon conventional technology and components that exist at present, are being performed at KEK.[2] Two kinds of modulators have been developed. First modulator, which is called Modulator #1 after this, has been built to study the practical application of Blumlein type modulator. The second modulator, which is called Modulator #2 after this, has been built to study a compact and high performance Blumlein modulator.

2 KLYSTRON

The X-band klystron development program at KEK had been originally designed for 80 MW peak power at 400ns pulse length. The rf parameters of the main linac were recently changed after reconsidering the rf system. The main parameters of the klystron developing at present are given in Table 1.[3]

Table 1. Specifications of X-band klystron

Operating frequency	11.424 GHz
RF pulse length	1.5µs
Peak output power	75MW
Repetition rate	120pps
RF efficiency	45%
Beam voltage	454kV
Beam current	367A
Perveance	1.2µ
Gain	53-56dB

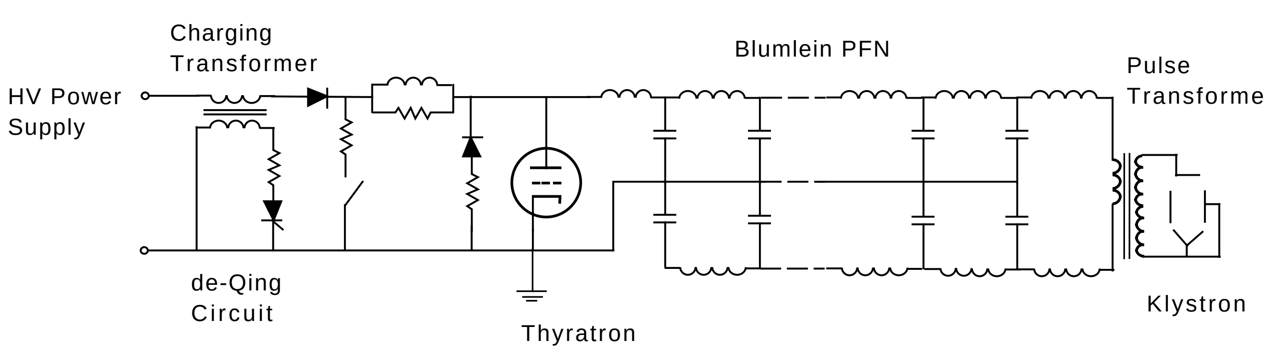

Figure 1. Circuit of the Blumlein type modulator.

3 BLUMLEIN CIRCUIT

The basic circuit of the Blumlein type modulator is shown in Figure 1. It consists of a conventional PT, a Blumlein PFN, a single-thyratron switch tube and a resonant charging circuit with a de-Qing circuit.

4 MODULATOR #1

4.1 Hardware

The modulator components shown in Figure 1 are all housed in air. The main parameters of the modulator #1 are given in Table 2. Maxwell mini double-ended capacitors were used as a PFN capacitor. The internal inductance of the PFN capacitor itself should be lower for faster discharge and it limits the shortness of the rise time. The internal inductance of this capacitor is approximately 20nH. Each section capacitor consists of two these capacitors which are placed in series to get 100kV. These capacitors have a standard value of 7nF and a rated voltage of 50kV. The thyratron EEV CX1937A with a rated voltage of 80kV was used as a switch tube which discharges the Blumlein PFN.

Table 2. Main parameters of the modulator #1

	unit	Design	Upgrade
Output pulse			
Secondary voltage(Max.)	kV	560	560
Secondary current(Max.)	A	503	503
Pulse width	μs	0.8	2.4
Flat-top	ns	400	1500
Repetition rates	pps	50	50
Pulse transformer			
Step-up ratio		1:8	1:8
Blumlein PFN			
PFN impedance/line	Ω	8.7	17.4
No. of sections		13	20
Inductance/section	μH	0.265	1.06
Capacitance/section	nF	3.5	3.5
Total capacitance	nF	91	280
Charging voltage(Max.)	kV	70	70

4.2 Output pulse waveform and circuit analysis

The solid line in Figure 2 shows an example of the klystron voltage waveform. An output pulse with a peak voltage of 470kV, a rise time(10%-90%) of 350ns, a flat-top width(flatness ±1%) of 400ns and a fall time(10%-90%) of 350ns was successfully generated. The rise time is a sufficiently short because the rise time of the requirement is less than 400ns.

We have analyzed the modulator circuit by a simulation method. The broken curve in this figure shows result simulated by a computer code Micro-Cap IV. The simulation gives a good fit to the measured data. From this analysis, it was found that total distributed capacitance in the pulse transformer, the tank and the klystron is about 180pF. This large value mainly limits the rise time of output pulse. The calculated values of distributed capacitances for the klystron and the PT are about 80pF and 40pF, respectively.

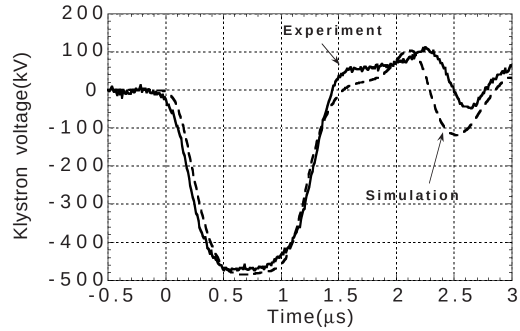

Figure 2. Output pulse waveform at the klystron.

4.3 Upgrade

We upgrade the modulator #1 to produce a pulse with a flat-top of 1.5μs. To increase the pulse width, the number of the PFN section is increased up to 20. Each line is made in two parallel lines to increase the value of the section inductance in order to improve the PFN characteristic. The charging transformer and the PT are also remade. The parameters of the upgrade modulator are given in Table 2. We simulated the output pulse waveform by using circuit parameters obtained by the circuit analysis above subsection. Figure 3 shows the result for a charging voltage of 70kV. The simulation shows that an output pulse with a rise time(10%-90%) of 350ns and a flat-top width of more than 1.5μs can be achieved.

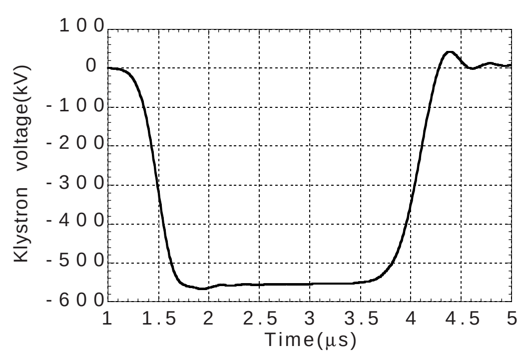

Figure 3. Output pulse waveform simulated by a computer code Micro-Cap IV.

5 MODULATOR #2

5.1 Hardware

The modulator components shown in Figure 1 are all housed in a cylindrical stainless oil tank which also mounts the klystron. This allows to make all circuits significantly compact, and also to make circuit wiring short. The slow rise time caused by stray inductance of wiring is therefore improved and it makes modulator efficiency better. Figure 4 is a photograph of the modulator #2. The size of the oil tank is 1.8m in diameter and 1.6m in height. The thyratron EEV CX2199 with a rated voltage of 100kV was used as a switch tube. For the Blumlein PFN, a compact double-ended capacitor with a capacitance of 1.9nF, a rated voltage of 80kV, a voltage reversal of 65%, an internal inductance of 40nH and a design life of $2x10^8$ shots was developed by Maxwell Energy Products, Inc.. The size of the capacitor is 4''wide x 6''deep x 10.25''high. The main parameters of the modulator are given in Table 3.

Table 3. Design parameters of the modulator #2

Output pulse	
Secondary voltage(Max.)	560kV
Secondary current(Max.)	503A
Pulse width	700ns
Flat-top	400ns
Repetition rates	50pps
Pulse transformer	
Step-up ratio	1:7
Blumlein PFN	
PFN impedance/line	11.5Ω
No. of sections	16
Inductance/section	252nH
Capacitance/section	1.9nF
Charging voltage(Max.)	80kV

Figure 4. Photograph of the modulator #2.

5.2 High-voltage test

A preliminary test has been performed to confirm the performance of the modulator. The secondary side of the PT was connected to a 1120Ω ceramic resistor. The modulator was operated up to a charging voltage of 80kV without any faults. Figure 5 shows the output waveforms obtained for a charging voltage of 40kV. An output pulse with a peak voltage of 280kV, a rise time(10%-90%) of 210ns, a flat-top width(flatness ±4.5%) of 400ns and a fall time(10%-90%) of 280ns was successfully generated.

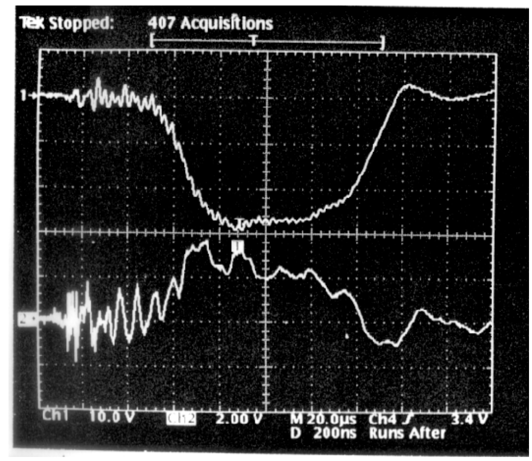

Figure 5. Output pulse waveform at the resistor load.
Upper trace: Output voltage(100kV/div)
Lower trace: Output current(200A/div)
Horizontal: 200ns/div

6 FUTURE PLANS

The upgrade work of the modulator #1 is now in progress and will be completed on October, 1998. We plan to test the modulator #2 connecting to a XB72K klystron to confirm its performance in this winter. In order to reduce both production costs and spaces of the modulators, we make a design study of the modulator operating two or four klystrons.

REFERENCES

[1] JLC Design Study Group, "JLC Design Study," KEK Report 97-1, 1997.

[2] H. Mizuno, T. Majima, S. Sakamoto and Y. Kobayashi, "A Blumlein type Modulator for a 100MW-class X-band klystron," Proc. of the Eupopean Particle Accelerator Conference, 1994.

[3] Y.H. Chin et al., "The 120 MW X-band Klystron Development at KEK," Proc. of the Eupopean Particle Accelerator Conference, 1998.