Blumlein-type X-band Klystron Modulator for Japan Linear Collider

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Abstract

A Blumlein-type X-band klystron modulator using magnetic-pulse-compression (MPC) techniques was designed and constructed relevant to the future Japan Linear Collider (JLC) project. This modulator has been designed to produce pulses that are 200-ns wide, 600-kV peak voltage, 1200-A peak current and a short rise time of ~ 70 ns with a repetition rate exceeding 200 Hz. To realize a compact modulator, a spiral structure was adopted to conductors of the triaxial Blumlein. Special care was taken regarding the location of the magnetic switch and the charging reactor in order to eliminate any undesirable voltage during the charging process. Details concerning this X-band klystron modulator and its preliminary performance are described.

I. INTRODUCTION

An e^+e^- linear collider in the TeV region (JLC project) has been proposed as a post-TRISTAN project [1,2]. Considering the relation which governs the design of a linear collider, an accelerating gradient of the order of at least 100 MV/m is required for the facility to be of reasonable scale. Achieving this high gradient requires a high-power microwave source with a peak output power of ~ 150 MW/m at a frequency of 11.4 GHz [2]. The development of high-power X-band klystrons using conventional technology was started for this purpose [3]. A 30-MW model of this X-band klystron was high-voltage conditioned using one of the modulators prepared for the KEK test accelerator facility (TAF) which was established in 1987 to pursue R&D technology for future linear colliders [4]. Although processing with 2-μs and 2-Hz pulses was successful [3], the development of an X-band klystron modulator using MPC techniques [5] was initiated in order to supply very short pulses (~ 200 ns), since the required pulse flat-top is of the order of 100 ns [2].

Two types of modulator designs using MPC techniques are considered because of their very short rise-time capability and high reliability; they consist of only passive components, such as saturable inductors, capacitors and Blumlein. One is a semi-conventional-type modulator which comprises a pulse-forming network (PFN), a pulse transformer and magnetic switches (see Fig. 1). A detailed description is given in ref. [6]. The other is a Blumlein-type modulator (see Fig. 2). Since the impedance of the Blumlein is half that of the klystron load, this type modulator seems to have some advantage in realizing a very short rise time which is generally very difficult for a high-impedance load.

This paper describes the Blumlein-type X-band klystron modulator and its preliminary performance tests.

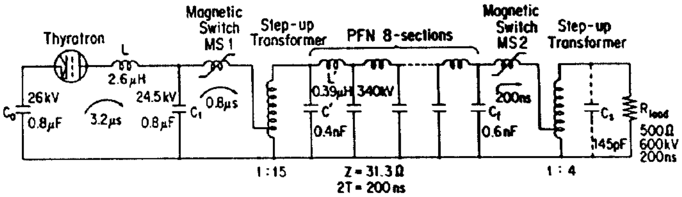

Figure 1. Simplified diagram of the X-band klystron modulator using a PFN, pulse transformer and magnetic switches.

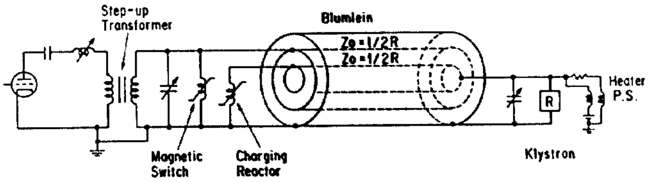

Figure 2. Simplified diagram of the Blumlein-type modulator.

II. BLUMLEIN TYPE X-BAND KLYSTRON MODULATOR

A. Modulator Specifications

The specifications of the X-band klystron modulator are listed in Table 1.

Table 1
Specifications of the X-band klystron modulator

Output pulse voltage range	400 ~ 600 kV
Output pulse current (Max.)	1200 A
Output impedance	500 Ω
Rise time	less than 100 ns
Pulse length (flat-top)	longer than 100 ns
Pulse amplitude drift	less than 1 %
Jitter	less than 5 ns
Pulse repetition rate	200 pps

The output impedance of the modulator is strongly dependent on the microperveance of the klystron. Although the impedance of the prototype X-band klystron is of the order of several kΩ, the impedance of the modulator was designed to be 500 Ω for the following reasons: 1) Since we are in the very first R&D stage of using the X-band klystron, we must consider the lowest probable value of the klystron regarding impedance in order to prepare for any change in its design.

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2) In order to reduce the construction costs of the future linear collider, simultaneous power feeding to several klystrons from a single modulator is inevitable, which results in a relatively low impedance. 3) For an efficient production of pulses with a very short pulse flat-top (~ 200 ns) a lower impedance is preferable, since a rather high impedance (several kΩ) results in a longer rise time (more than 500 ns) due to the estimated stray capacitance around the output circuit and klystron socket (~ 150 pF).

The limits to pulse amplitude drift and pulse height deviation are determined from the requirement of acceptable phase modulation of the microwave source (~ 5°). A relativistic beam voltage of 600 kV lessens the requirements on the pulse-top flatness and amplitude stability, since the velocity of electron beams in the X-band klystron is not so sensitive to changes in the beam voltage within this relativistic voltage range.

B. Blumlein-type Modulator

Although the Blumlein-type modulator may seem to be very simple (see Fig. 2), careful attention has been paid to the design, especially to the location of the magnetic switch and the charging reactor as well as to the triaxial Blumlein.

Figure 3 shows the simulated output waveforms for two different locations of the magnetic switch and the charging (bypass) reactor. Since we don't want any undesirable voltage during the charging process, the location of the magnetic switch and the charging reactor is very important in order to eliminate it.

Figure 4 shows a cut-away view of the triaxial Blumlein. In order to realize a compact, high-impedance Blumlein, a spiral structure was adopted for the inner conductors. The number of windings for these spiral conductors was designed so as to cancel their resultant magnetic flux in order to make sure of its Blumlein action. The final design parameters of the Blumlein are as follows: The central conductor is a 30-turn spiral conductor with a diameter of 290 mm. The middle conductor is also a spiral conductor with 22 turns and 400 mm in diameter. The outer-most conductor is an aluminum cylinder with an inner diameter of 550 mm. The total length of this Blumlein is 1 m.

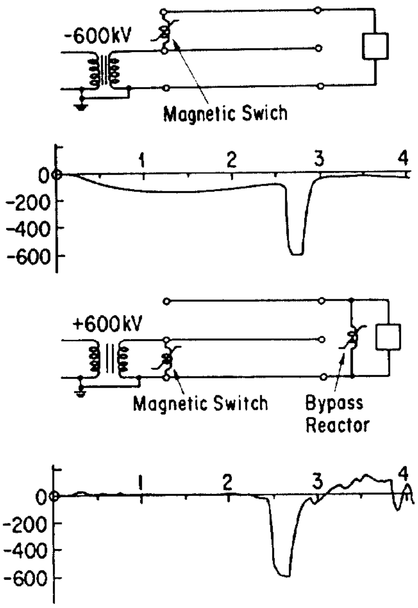

Figure 3. Blumlein-type modulators with two different locations of the magnetic switch and their simulated output waveforms.

III. PERFORMANCE TEST

A. Preliminary Test

Before proceeding to tests at a full voltage of 600 kV, a preliminary test was performed at ~ 200 kV in order to

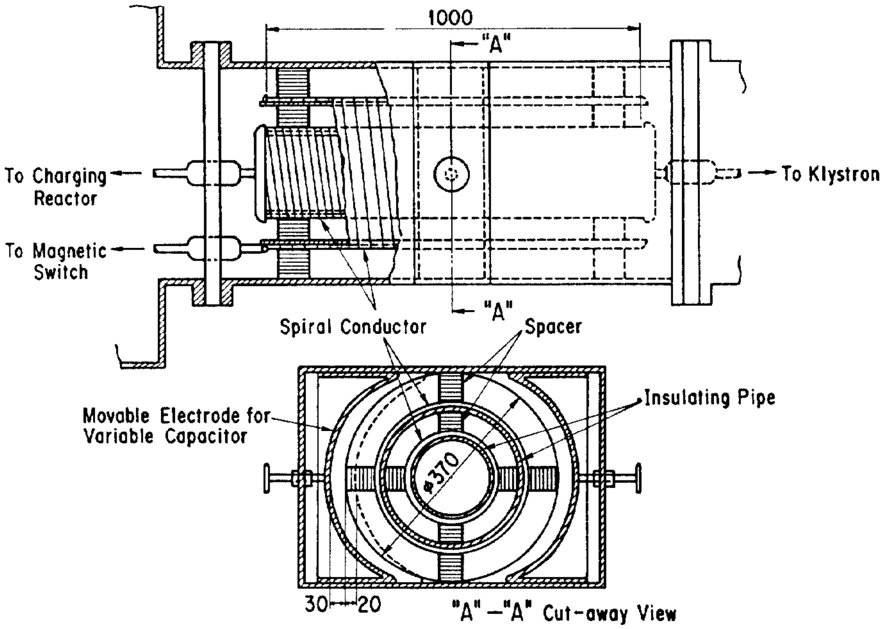

Figure 4. Cut-away view of the triaxial Blumlein.

confirm the above-mentioned design. Figures 5 and 6 show the input- and output-side voltage waveforms of the Blumlein, respectively. The input pulse with a 1.1 μs pulse width and a 210 kV peak voltage has been successfully compressed down to 260 ns with a peak voltage of 178 kV. An expanded output voltage waveform is shown in Fig. 7. Although a pulse flat-top length of 155 ns is sufficient for our use, a pulse rise time of 138 ns is rather longer than we expected. The main cause of this relatively long rise time is the stray capacitance of the magnetic switch. We must, therefore, reduce this stray capacitance in order to realize a very short rise time.

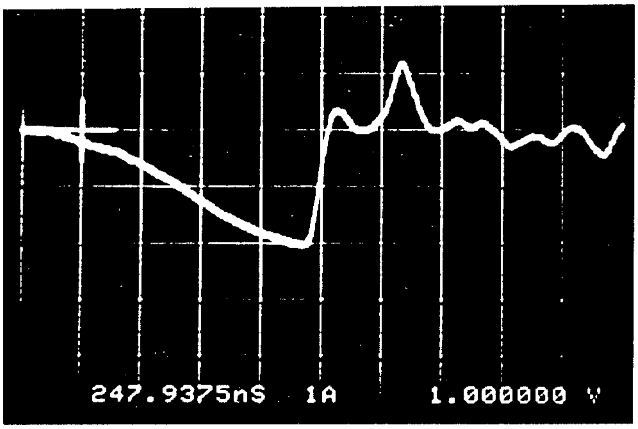

Figure 5. Input voltage waveform of the triaxial Blumlein. (vert. 100 kV/div., hor. 200 ns/div.)

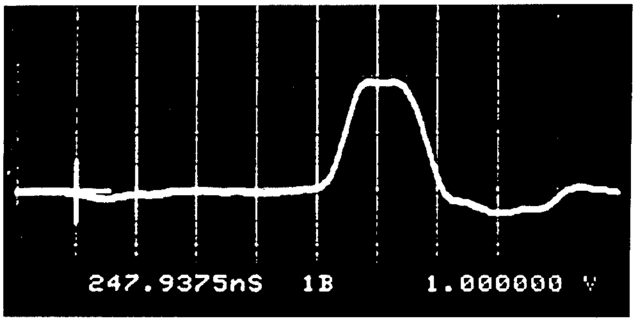

Figure 6. Output voltage waveform of a triaxial Blumlein. (vert. 100 kV/div., hor. 200 ns/div.)

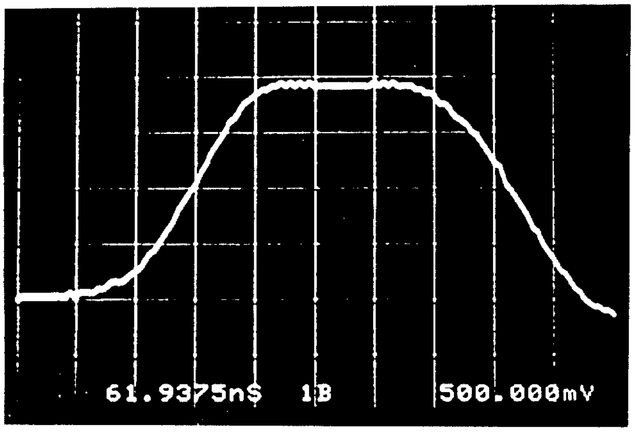

Figure 7. Expanded output voltage waveform of the triaxial Blumlein (vert. 50 kV/div., hor. 50 ns/div.)

B. Full Voltage Test

Since the preliminary tests of the Blumlein-type modulator have been very hopeful, we are now proceeding to carry out tests at full voltage (~ 600 kV). Figure 8 shows the locations of individual components in the 600-kV compatible Blumlein-type modulator. Although the core material of the magnetic switch and the charging reactor in the preliminary test is Co amorphous, we are planning to use Fe amorphous cores because of a high ΔB capability which enables us to reduce the size of the magnetic switch as well as the charging inductor. A full-voltage test of this modulator will start soon.

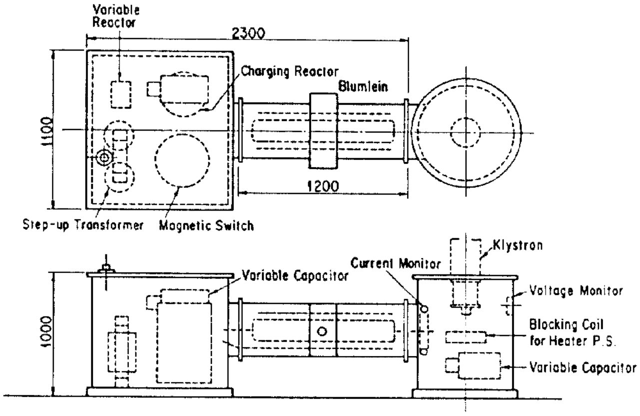

Figure 8. Location of individual components in the 600-kV compatible Blumlein-type modulator.

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