R&D ON AN X-BAND KLYSTRON MODULATOR FOR JAPAN LINEAR COLLIDER

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Abstract

Design considerations of an X-band klystron modulator for the future JLC (Japan Linear Collider) project are presented. This modulator has been designed to produce pulses that are 200-ns wide, 600-kV, 1200-A peak current and a short rise time of ~90 ns; it is based on magnetic-pulse-compression techniques with a very high peak-power capability and a repetition rate exceeding 200 Hz. R&D on amorphous core materials for magnetic compressors and solid-state devices (such as GTO and MAGT) for a discharging switch to realize an efficient and reliable modulator are currently being undertaken.

Introduction

As a post-TRISTAN project, an $e^+ e^-$ linear collider in the TeV region (JLC: Japan Linear Collider) has been proposed to reach energies beyond that of LEP.[1,2] It requires an accelerating gradient on the order of at least 100 MV/m for the facility to be of reasonable scale. Achieving this high field gradient requires high-power microwave sources with a peak output power of about 150 MW at a frequency of 11.4 GHz (see Fig. 1).[3]

To realize this high-power microwave source the development of high-power X-band klystrons using conventional technology was started.[4] Although the studies of a two-beam accelerator (TBA) scheme using free-electron laser technology were also started at KEK,[5] X-band klystrons could be in use at the first phase of the JLC.

For a prototype X-band klystron we expect an output power of 30 MW at the maximum design voltage of 450 kV. The diode model of this tube 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.[6] Processing with 1-μs and 2-Hz pulses has increased to a voltage of 450 kV, which corresponds to a beam power of 81 MW.[7] Although this processing was successful, development of an X-band klystron modulator using magnetic-pulse-compression techniques[8] was initiated in order to supply very short pulses (~200 ns), since the required pulse flat-

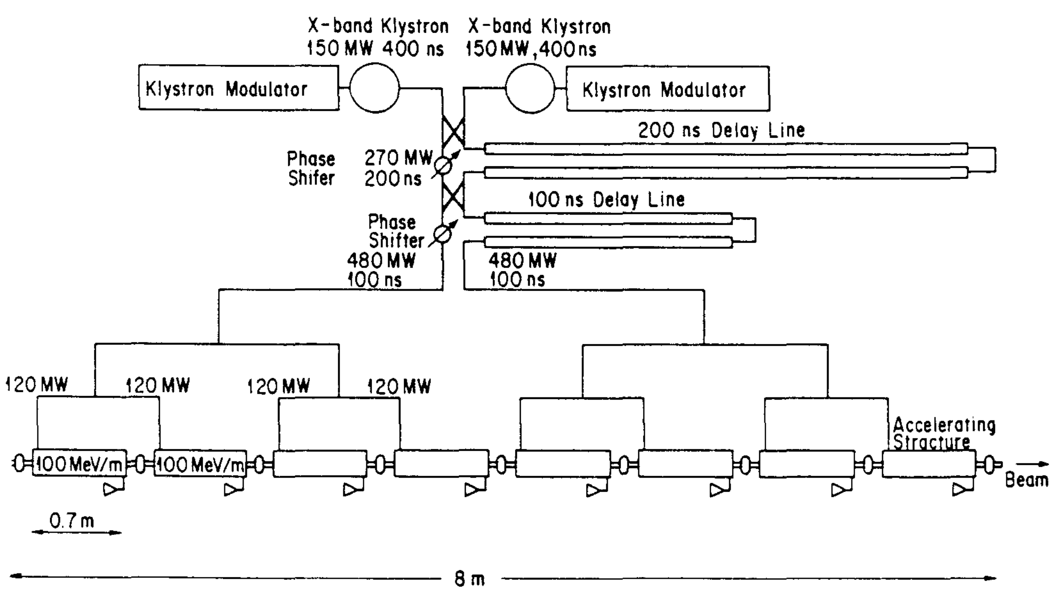

Fig. 1. Conceptual drawing of the JLC microwave distribution system.

top is on the order of 100 ns. Details of this X-band klystron modulator are described.

Modulator Specification

Specifications of the X-band klystron modulator are listed in Table I. Although the impedance of the prototype X-band klystron is on 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 have to prepare for any change of its design. Therefore, the lowest probable value of the klystron impedance should be taken into account for the modulator design. 2) Since a rather high impedance (several kΩ) results in a longer rise time (more than 500 ns) due to the estimated stray capacitance (~150 pF) around the output circuit and klystron socket, a lower impedance is preferable for the efficient production of short pulses (~200 ns). 3) Simultaneous power feeding to several klystrons by a single modulator is being considered for the future linear collider in order to reduce construction costs, resulting in a relatively low impedance.

TABLE I
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	< 100 ns
Pulse length (flat top)	> 100 ns
Pulse height deviation from flatness	±1.0 %
Pulse amplitude drift	< 2 %
Jitter	< 5 ns
Pulse repetition rate	200 pps

The requirement for an acceptable phase modulation (~5 °) of the microwave source limits the pulse-height deviation and pulse-amplitude drift of the modulator. Although, the microwave circuit design of the X-band klystron is tentative, a relativistic beam voltage of ~600 kV lessens the requirements on the pulse-top flatness and amplitude stability.

Circuits of the X-band Klystron Modulator

Two types of modulator designs using magnetic-pulse-compression techniques are considered because of their very short rise-time capability and high reliability, since they consist of only passive components, such as saturable inductors, capacitors and Blumlein.

Semi-conventional Type Modulator

A semi-conventional-type modulator (a combination of a pulse-forming network (PFN), pulse transformer and magnetic switches) has been intensively studied because of its ease in adjusting pulse-top flatness (see Fig. 2). The stored energy of capacitor C_0 is transferred into another capacitor (C_1) through a thyratron, then successively to the PFN capacitors by increasing the voltage through a 1:15 step-up transformer, and finally to a klystron through a 1:4 step-up transformer. The compression factor of each stage is 1/4. Assuming a stray capacitance of ~145 pF at the secondary circuit of the final step-up transformer, the output voltage of this circuit was simulated (see Fig. 3).[9] A rise time of ~90 ns is expected. The result of the simulation is very encouraging regarding the use of the X-band klystron modulators.

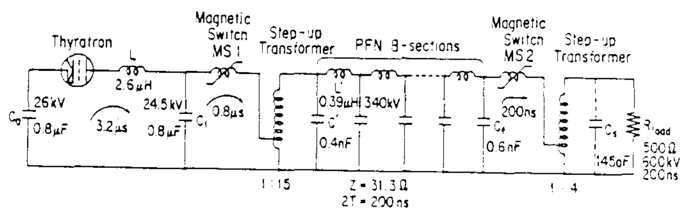

Fig. 2. Simplified diagram of the X-band klystron modulator using PFN, pulse transformer and magnetic switches.

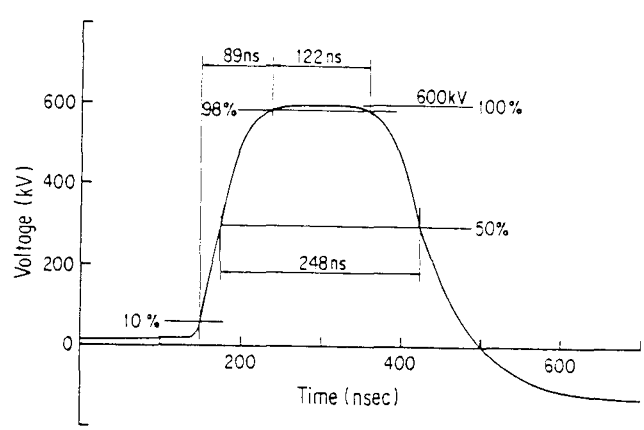

Fig. 3. Simulated output voltage of the X-band klystron modulator.

Blumlein Type Modulator

A Blumlein-type modulator (see Fig. 4) seems to have some advantage, since the impedance of the Blumlein is half that of the klystron load. The location of the magnetic switch and the charging reactor is important in order to eliminate any undesirable voltage during the charging process.[10]

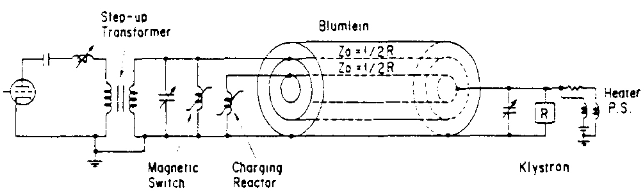

Fig. 4. Simplified diagram of the Blumlein-type modulator.

R&D Items

Although the simulated result is very hopeful, there are several R&D items required in order to put into use this type of modulator for the future linear collider.

Amorphous Core

Since the required pulse-repetition rate is 200 Hz, a temperature increase caused by power loss at the inductor core is a key issue regarding this type of magnetic compressor. Although a low-loss Co amorphous core is sufficient for our modulator use from a technical point of view, the price is a problem. Since more than 2000 X-band klystrons are used in the JLC, R&D on a low-cost amorphous core (for example; Fe amorphous core with a very thin thickness[11]) suitable for our use is inevitable.

Switch Device

If we endure the replacement of failed switch devices for the future JLC modulators several times per month the lifetime of each switch device should be on the order of 10^{12} shots, which is much beyond the present technology. Therefore, R&D on a switching device with a longer lifetime is a key point in realizing the JLC project. Solid sate devices, such as GTO (Gate Turn Off) thyristers, IGBT (Insulated Gate Bipolar Transistor) and MAGT (MOS-Assisted Gate Turn Off) thyristers, are good candidates.[12] We have started R&D on solid-state switching devices (MAGT) capable of large di/dt (5000 ~ 10000 A/μs).

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