# The Beam Pulsing System for the 600 kV Neutron Generator

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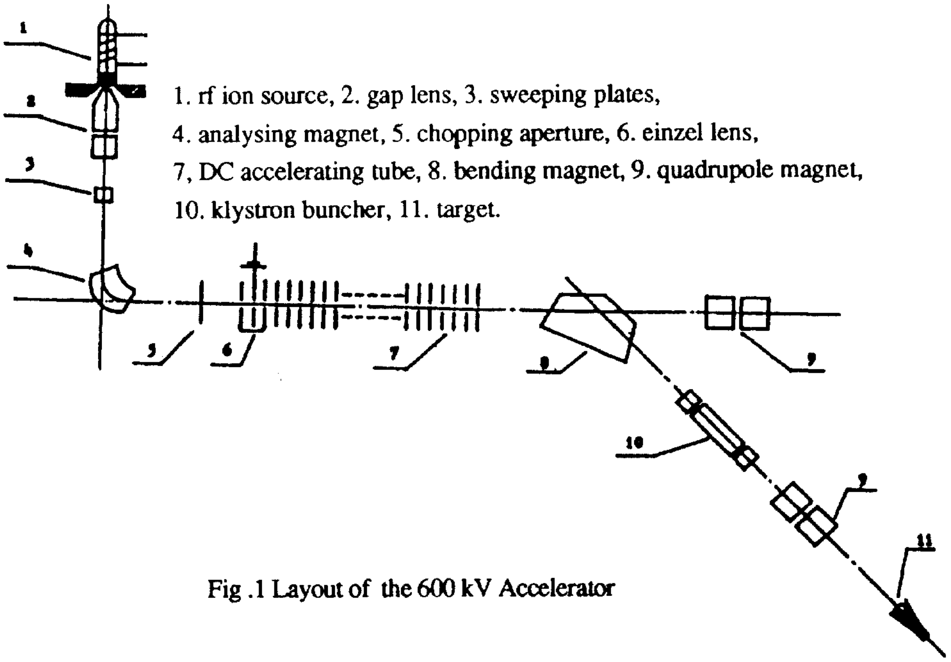
*Abstract*

The design details of the beam pulsing system for the 600 kV ns pulsed neutron generator is presented. A rf harmonic chopper operating at the frequency of 0.75 MHz and 6.75 MHz is adopted to increase the chopping utilization and located at the high voltage end. The 6 MHz klystron buncher is situated at the earth potential after acceleration. Computer simulations show that the duration of ion bursts is expected to be 1.0-1.5 ns.

## 1. INTRODUCTION

A 600 kV accelerator is being developed at the China Institute of Atomic Energy. To use time of flight method in neutron physics experiments, it is required to generate short duration of ion bursts. Therefore, a beam pulsing system has been designed for this machine at Peking University.

Several kinds of bunchers can be used to compress the dc beam into short bursts, such as klystron buncher[1-4], double-drift harmonic buncher[5-7] and single gap harmonic buncher[8-10], etc. After some calculations and comparisons, we chose klystron type buncher and put it at the earth potential after accelerating column. The main reason for bunching high energy beam is that it will ease the rf source of intensity beam for its large energy spread. But, the disadvantages are that it increases greatly the bunching rf power consumption and requires high stability of the accelerating voltage.



1. rf ion source, 2. gap lens, 3. sweeping plates,
4. analysing magnet, 5. chopping aperture, 6. einzel lens,
7, DC accelerating tube, 8. bending magnet, 9. quadrupole magnet,
10. klystron buncher, 11. target.

Fig .1 Layout of the 600 kV Accelerator

To reduce the background of the bunched beam, we set a chopping system at the high voltage end. The chopping utilization of sine wave chopper is usually 50%. However , if an additional odd harmonic wave is applied to the sweeping plates the chopping utilization can be improved by the percent of 20-25. After some calculations, we chose the ninth harmonics. i.e., its frequency is 6.75 MHz.

## 2. GENERAL DESCRIPTION

The basic design considerations for the bunching and chopping system is the production of ion bursts of duration less than 1.5 ns (FWHM) at the repitition rate of 1.5 MHz.

The beam pulsing system is shown in Fig. 1. The deuteron beam of 3-6 mA is extracted from a rf source and accelerated to 30 keV by a gap lens. After that the beam is focused to a waist, where a pair of sweeping plates are inserted. Later on, the chopped beam passes through a 90° bending magnet to remove the unwanted particles. A chopping aperture of 5 mm in diameter is located in the image space of the analyzing magnet. To avoid the Mobley compressing effect, the beam should be swept in the vertical direction of the magnet. The duration of chopped bursts is 50 ns so that it can meet the approximately linear range of the 6 MHz bunching sine wave. The energy reaches to 600 keV after passing through the accelerating column, at the entrance of which a three-aperture einzel lens is incorporated.

Two beam transport lines are designed. The straight line will be used for neutron irradiations, and the 45° beam line for time of flight experiments. The klystron buncher is installed on the 45° beam line at the image point of the 45° bending magnet. Then focussing is provided by a magnetic quadrupole doublet to produce small beam spots at the final target.

The buncher works at the frequency of 6 MHz, and the length of it is chosen to obtain the proper conditions for bunching 300 keV deuterons. The distance from the buncher to the neutron production target is 2.5 M. This design would allow 50 ns and 300 keV deuteron beams to be compressed to the duration less than 1.5 ns at the final target.

## 3. BUNCHING AND CHOPPING SYSTEMS

### 3.1 *Bunching System*

The klystron buncher is a type of two gap buncher. The distance between the two gaps is

$$L = 0.5\beta cT \qquad (1)$$

where $\beta c$ is the velocity of the central particle, T is the period of the bunching sine wave. This choice means that the transit time of a particle through the tube is equal to one half of the period of the bunching wave. Thus, the particle which encounters accelerating fields at the first gap receives an equal accelerating field at the second gap.

Because of the particle high energy, more problems which are different from what of the low energy buncher should be considered carefully: the cooling system, the electric break down as well as the high quality factor Q of the buncher cavity, etc.

To estimate the pulse width of the bunched beam, a computer program LMOVE[11] has been developed. This program calculates bunching systems consisting of the following elements: klystron buncher, double-drift harmonic buncher, single gap harmonic buncher, dc accelerating tube and drift space.

For the klystron buncher calculations, the mathematics formulas used in LMOVE are as following: suppose the sine wave phase, when the central particle passing through the center of the buncher, is $\Phi_s$ . At the first gap the energy gain of arbitrary particle is

$$\Delta E = QVm\ T\cos(\Phi_s - \pi/2 + \omega l/v + \Phi_0) \qquad (2)$$

where, $T=\sin[\omega g/(2v)]/[\omega g/(2v)]$ is the transit time factor, $\Phi_0$ is the initial phase angle, L=2l is the distance between the two gaps, and g is the effective gap. From equation (2) it can be seen that, the particle energy depends on its phase, and its phase depends on its energy. So, we solve this equation by iterative method.

From the first gap to the second one, the particle flies a distance 2l. The particle energy keeps unchanged, but the phase shift is $2l\omega/v$.

At the second gap, the phase of the particle does not change, but its energy varies by a quantity:

$$\Delta E = QVm\ T\cos(\Phi_s - \pi/2 + \omega l/v + \Phi_0) \qquad (3)$$

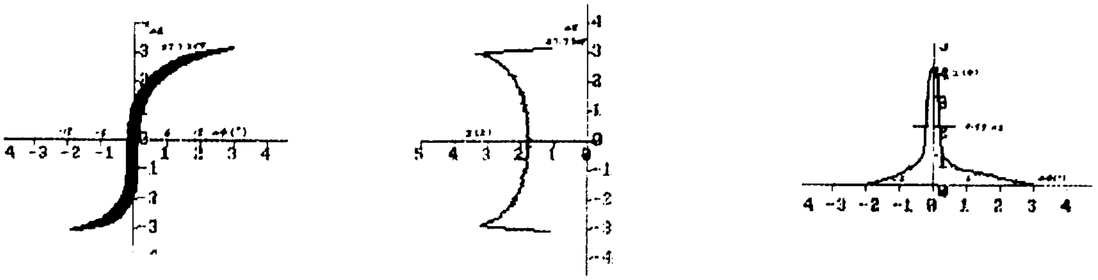
After the modulations by the buncher, the beam transits the remaining space to the target and is compressed in a short duration. The longitudinal emittance, the beam current pulse and the energy spectrum are shown in Fig. 2.

### 3.2 *Chopping System*

If there is only existing fundamental wave applied on the sweeping plates, the relationship between the time length $\tau_c$ of the chopped beam and the amplitude $V_0$ of the sine wave is

$$V_0 = 2E_0\ g\ b/[l_s S\ \sin(\omega\tau_c/2)] \qquad (4)$$

where $E_0$ is the particle energy; $b=r_0+a$, $r_0$ is the aperture radius, a is half width of the beam waist at the aperture; g is the gap between the plates; $l_s$ is the longitudinal length of the plates; S is the distance from plates to the chopping aperture. Suppose



(a). Longitudinal phase (b). Energy spectrum (c). Current pulse

Fig. 2 Calculated Results

the beam energy is 30 keV, the chopped time duration of the beam is 50 ns, the chopping voltage will be 2.9 kV.

After adding the 9th harmonics to the chopper, the combined voltage is[12]

$$V(t) = C[\sin\omega t' + b_k \sin(\omega t' + \psi)] \quad (5)$$

In this case, the displacement of the central particle at the aperture is

$$X_0(t) = C[\sin\omega t' + b_k \sin(k\omega t' + \phi)] \quad (6)$$

where

$$C = A_1 T_F(\omega) K(\omega) S$$

$$t' = t - S/v - \delta\omega)/\omega$$

$$b_k = [T_F(k\omega)/T_F(\omega) [K(k\omega)/K(\omega)] B_k$$

$$T_F(\omega) = (\sin\phi/\phi_1)[\sin(\phi+\phi_1)/(\phi+\phi_1)]$$

$$K(\omega) = [1 + tg^2 \delta(\omega)]$$

$$\phi = \omega l/(2v)$$

$$\phi_1 = \omega l_1/(2v)$$

$$A_1 = V_1(l + l_1)/(2V_0 g)$$

$$B_k = b_k/\{[T_F(k\omega)K(k\omega)]/[T_F(\omega)K(\omega)]\}$$

Calculated values show that if k=9, $b_K=0.112$, the chopping utilization has a maximum value $\eta_c \approx 75\%$, and the amplitude of the harmonics is $V_k = V_0 B_k = 910$ volts.

## 4. DEBUNCHING EFFECTS DUE TO BEAM ENERGY SPREAD

It is known that in an ideal system with monoenergetic ion beam infinite peaks in target current could occur under certain conditions. In practice, however, monoenergetic beams can not exist. Ion beams in general always possesses energy spread which is introduced by the ion source, the process of sweeping the beam across an aperture and the instability of high voltage. The time spread and the loss of amplitude of bunched pulses at the target will be caused by energy spread. The calculated results are shown in Table 1.

Table 1

| $L_b$(M) <br> $\tau_c$(ns) <br> dE(eV) | 2.0 | 2.5 | 3.0 |
|---|---|---|---|
| 300 | 0.45 | 0.60 | 0.68 |
| 400 | 0.65 | 0.75 | 0.90 |
| 500 | 0.82 | 1.00 | 1.21 |
| 600 | 1.01 | 1.17 | 1.33 |
| 800 | 1.32 | 1.60 | 1.72 |

## 5. SYSTEM ELECTRONICS

A block diagram of electronics for the bunching and chopping system is given in Fig. 3.

The 6 MHz crystal oscillator provides the basic frequency for the complete system. Three output circuit branches are provided. One branch outputs the rf power of 6 kW and the frequency of MHz fed to the high energy buncher. In this branch a full 360°variable phase shift circuit is incorporated.

The signal from the rf power of 200 Watts and 0.75 MHz is fed to the chopper plates as fundamenal wave. A 360° variable phase shift circuit is included also.

The harmonic wave for the chopper is from the third branch, which output power is 200 Watts and frequency 6.75 MHz.

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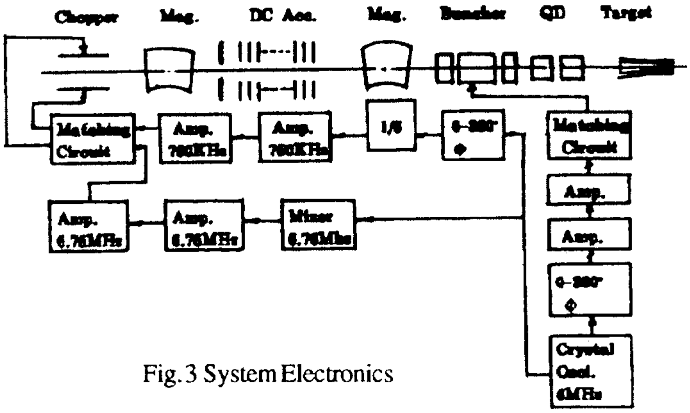

Fig.3 System Electronics

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