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SNU 1.5 MV Van de Graaff Accelerator (V)

—On the Operation of the High Voltage Stabilization System—

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SNU 1.5 MV 반데그라프 가속기 (V)

——고전압 안정화 계통의 동작——

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Abstract

A high voltage stabilization system for the SNU 1.5MV Tandem Van de Graaff accelerator was set up and its operational characteristics were examined and optimized. The optimum parameters of beam transport system were experimentally determined, and under the proper condition the accelerated proton beam current of 350nA was obtained at the target chamber. Without the high voltage stabilization the observed magnitude of voltage fluctuation was $\Delta V/V=5.2\times10^{-3}$ without ion beam and 7.2×10^{-3} with ion beam, respectively, and its apparent ripple frequency for voltage fluctuations was about 3Hz or less. Through the optimized operation of the high voltage stabilization system, the terminal voltage fluctuation was reduced to $\Delta V/V=2.45\times10^{-4}$ and the energy stability with $\Delta E/E=2.44\times10^{-4}$ was steadily maintained at the 247.3kV terminal voltage, and the stabilization factor was deduced to be 29.4.

요 약

SNU 1.5MV 직렬형 반데그라프 가속기의 고전압 안정화 계통을 설치하여 그 동작 특성을 파악하고 최적화하였다. 이온빔 수송계통의 최적 운전 조건을 단계적인 실험을 통하여 결정하였으며 적절한 운전 조건하에 표적함에서 350nA의 가속된 양성자빔을 얻었다. 고전압을 안정화하지 않았을 때의 고전압 변동은 이온빔을 가속하지 않을 때와 가속할 때 각각 $\Delta V/V=5.2\times10^{-3}$, 7.2×10^{-3}이었으며 그 변동 주파수는 3Hz이하였다. 터미날 전압 247.3kV에서 고전압 안정화 계통의 최적 운전을 통하여 터미날 전압의 변동은 $\Delta V/V=2.45\times10^{-4}$으로 줄었고 에너지 안정도는 $\Delta E/E=2.44\times10^{-4}$으로 유지되었으며 이 때의 안정화 계수는 29.4였다.

I. Introduction

The most important property of Van de Graaff accelerator is highly stabilized homogeneous beam energy. Therefore the high voltage stabilization system is one of the most important equipments. Basically, the high voltage stabilization system works as an active feedback compensator. It senses fluctuations in the terminal voltage and applies compensative corrections to that voltage. Fluctuations of the terminal voltage can be sensed by the various devices such as differential slit located after the analyzing magnet, capacitive pick-up plate and generating voltmeter. There are also various methods for high voltage stabilization such as the application of grid controlled triode, slow control of the charging current and capacitive liner[1~3].

For the SNU 1.5MV Tandem Van de Graaff accelerator, the fluctuations of the terminal voltage are dominant below the frequency range of about 3Hz and that of high frequency is negligible. Thus, the high voltage stabilization system using a differential slit and a grid controlled triode was set up and its operational characteristics were examined.

The experiment described below was carried out at the terminal voltage below 300kV, but the results can be extended to the higher voltage range and applied to the corona system of other electrostatic accelerator.

II. Principle

The high voltage stabilization system consists of a grid controlled triode (6BK4), differential beam slit located after the energy analyzing magnet and energy stabilization circuit. Schematic diagram of the high voltage stabilization system is shown in Fig. 1.

The operation principle is as follows: A fractional change in terminal votage changes the ion beam energy, which results in a change in the deflection angle through the magnet and a displacement of the beam position at the differential slit. The unbalanced ion beam currents on the slit elements are fed into the differential amplifer of the voltage control circuit. It then changes the resistance to ground of the corona triode needle opposite the high voltage terminal. This allows the needle to draw, in response to the variation of the terminal voltage, more or less current from the high voltage terminal, which decreases or increases the terminal voltage. In this way a very stable ion beam energy is maintained.

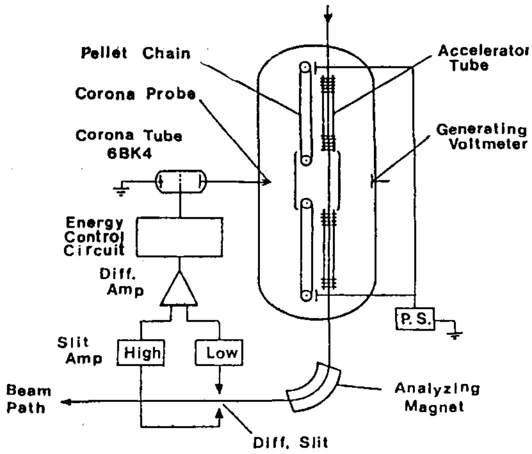

Fig. 1. High Voltage Stabilization System.

II. 1. Source of terminal voltage fluctuation

Analytically the terminal voltage is determined by the current equilibrium between charging current and load current[4]. Therefore, terminal voltage fluctuation may arise from the fluctuations in either current. Apparently fluctuation of the charging current is caused by the irregular motion of the charging chains which may be resulted in the mechanical nonuniformity along the chain loop and different length of chains[3,5]. Except the corona-dominant voltage region, the ion current and secondary electron load current in the accelerating tube will be main sources of load current fluctuation[6]. The variation of the ion current takes place when the power supplies of the beam handling components and the ion optical components are not stable, and that of secondary electron load current is caused by poor vacuum in the accelerating tube.

II. 2. The relation between energy and slit position

The force F on a particle with charge q moving with velocity v in a magnetic field (B) at right angle to the motion is given by $F=qvB$. The centripetal force F_c on a particle with mass m moving with a radius r is given by $F_c=mv^2/r$. Combining these two equations with the nonrelativistic expression for kinetic energy $E=mv^2/2$, the deflection radius becomes $r=(2mE)^{1/2}/qB$, and then

$$\frac{dr}{r}=\frac{dE}{2E}. \tag{1}$$

The beam path length in the magnetic field shown in the Fig. 2 is given by $S_m=r\theta$. The path length S_m may be regarded as constant for small changes of r and, i.e., $d(r\theta)=0$, and then

$$\frac{dr}{r}=-\frac{d\theta}{\theta}. \tag{2}$$

The combination with Eq. 1 gives

$$\frac{d\theta}{\theta}=-\frac{dE}{2E}. \tag{3}$$

For the differential beam slit located at a radius R_s from the center of the magnet is fixed,

$$R_s d\theta=dS_s \text{ and } \frac{d\theta}{\theta}=\frac{dS_s}{S_s}. \tag{4}$$

For small changes in the deflection angle, the arc and chord are almost equal. Then the variation of the beam position de on the slit equals to dS_s, and immediately $d\theta/\theta=-dE/2E=de/S_s$ Therefore the energy stability is given by

$$\frac{dE}{E}=-\frac{2de}{S_s}, \tag{5}$$

where the value of de can be determined by the experimental curve of the slit current versus position of slit element.

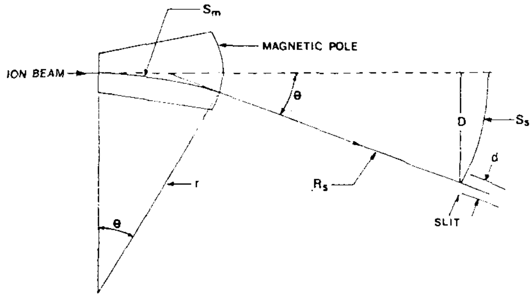

Fig. 2. Beam Path Through the Analyzing Magnet.

III. Set-up

As shown in Fig. 1, the high voltage stabilization system consists of insulated differential slit after the energy analyzing magnet, slit Log amplifier, corona needle probe fixed on inner wall of the pressure vessel opposite the high voltage terminal, and energy control circuit.

The analyzing magnet is used for the analysis of particular mass, energy and charge, and to transport the ion beam onto the target. This magnet is designed for double focusing with the entrance and exit angle of 26.5° for stigmatic condition[7]. It has the deflection radius of 16.5 cm, maximum magnetic field of 17.5kG in the gap(35mm), image and object distance of 33cm, and mass-energy product $ME/z^2=4$ with 90° bending angle, where M=particle mass in atomic units, E=particle energy in MeV, and z=number of elementary charge. This magnet is energized by an ultra-stable regulated current supply, and its maximum output current is 40A with the relative fluctuation of 1.9×10^{-4}.

The differential slit (BDSM-2, NEC) is made up of two plates, the high energy plate and the low energy plate, which sense the imbalance of the ion beam currents on the slit elements. Each slit element can be moved independently from

3mm over center to a maximum distance of 13 mm from center, and it is made of tantalum. It is electrically insulated from the drive assembly by ceramic washers[9].

The slit Log amplifier is a two channel Log amplifier that is designed to accept the 0.1~100nA input signals and provide the 0~6V output. It transfers the signals from each slit element to the energy control circuit[9].

The energy control circuit (ESC-2, NEC) compares the signals from the slit Log amplifier, determines the amount of imbalance, and sends a correction signal to the probe controller[9].

The probe controller (ESC-2, NEC) determines the grid voltage of the 6BK4 electron tube. The anode of the tube is connected to the corona probe located near the terminal and draws corona current of maximum 50μA from the terminal. The amount of the corona current is dependent on the grid voltage of the tube. The correction signal from the energy control circuit will either bring the grid voltage more positive, thus drawing more current from the terminal and bringing the terminal voltage down, or it will bias the grid more negative, thereby drawing less current from the terminal and allowing its voltage to rise to the desired setting[9].

In order to measure the terminal voltage, a generating voltmeter was fabricated and installed on the wall of the pressure vessel opposite the high voltage terminal. In order to determine the terminal voltage from its output signal, it was calibrated by use of known voltage sources and the resulted calibration equation is

$$V_t = 176.7 I_g + 3.2,$$

where V_t=terminal voltage in kV and I_g= generating voltmeter output in μA.

IV. Experiments

In order to determine the optimum parameters for beam handling components and ion optical components, all beam line components were set up step by step and operational parameters were determined for each step and those were tuned more precisely in connection with the successive step operation.

With no acceleration of ion beam, the high voltage was applied to the terminal and a small current was fed to each slit element of the differential slit by the external source. Variations of the terminal voltage, corona probe current and grid voltage of 6BK4 electron tube were examined under variation of the slit current. Using the results from these experiments, the high voltage stabilization system was activated. Under the operation of the high voltage stabilization system, in order to figure out the energy stability, the slit current was measured as a function of the position of the slit element.

V. Results and discussion

V.1. Analysis of the voltage fluctuations

The variation of charging current is caused by nonuniformity of the pellet chains, different length of pellet chains and minute discharge between pellet chains and equipotential plates etc.. The measured fluctuation of the charging current I resulted in $\Delta I/I = 1.8\times10^{-2}$, from which the fluctuation of the terminal voltage is deduced: $\Delta V/V = 8.0\times10^{-3}$. Its decrease is due to the smoothing effect of the terminal-to-ground capacitance of 63.9pF. Fluctuation of load current is mainly due to that of ion current and electron loading effect. The former is caused by the variation of the ion optical properities of ion optical components and the latter is caused by poor vacuum. When the ripple factor of the Einzel lens power supply was decreased to 2.5×10^{-3} from 2.0×10^{-2}, the fluctuation of the terminal voltage ($\Delta V/V$) was decreased to 1.4×10^{-2} from 5.0×10^{-2}. For the pressure of 3.8×10^{-6} Torr and 3.6×10^{-5} Torr in accelerating tube, the

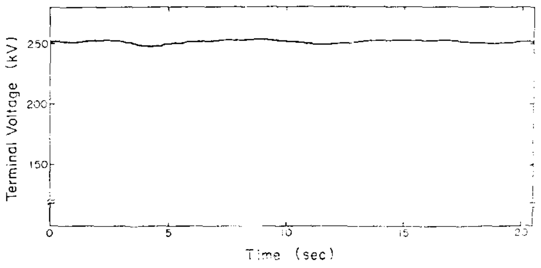

Fig. 3. Variation of Terminal Voltage without High Voltage Stabilization.

fluctuation of the terminal voltage ($\Delta V/V$) is 1.9×10^{-2} and 3.8×10^{-2}, respectively. Without activation of the high voltage stabilization system, the fluctuation of the terminal voltage is 5.2×10^{-3} without ion beam and 7.2×10^{-3} with ion beam. Frequency of the fluctuation is below about 3Hz as shown in Fig. 3.

V. 2. Acceleration and transportation of ion beam

Operational characteristics of the whole beam line components were examined and optimum operational conditions were determined. Under the proper condition with the H^- beam current of $3\mu A$ extracted from the ion source, the accelerated proton beam current of $350nA$ was obtained at the target chamber.

V. 3. High voltage stabilization

As shown in Fig. 4, when the current of high energy slit element is larger than that of

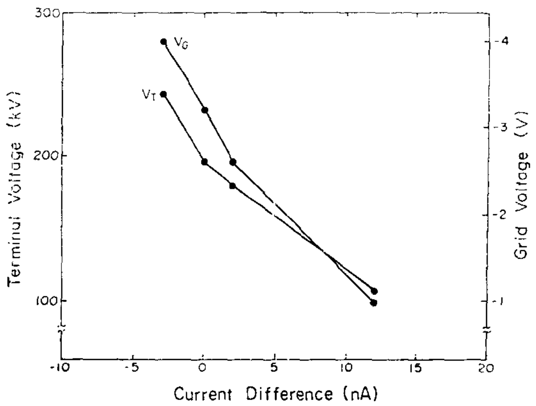

Fig. 4. Terminal Voltage as a Function of Current Difference (=high energy slit current - low energy slit current).

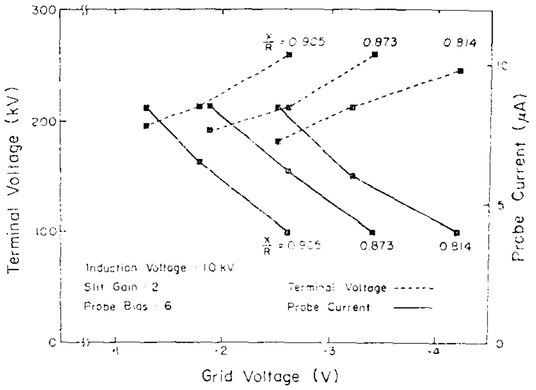

Fig. 5. Terminal Voltage and Probe Current as a Function of Grid Voltage, where x=the distance between the center of terminal and the corona needle, R=the diameter of grounded pressure vessel.

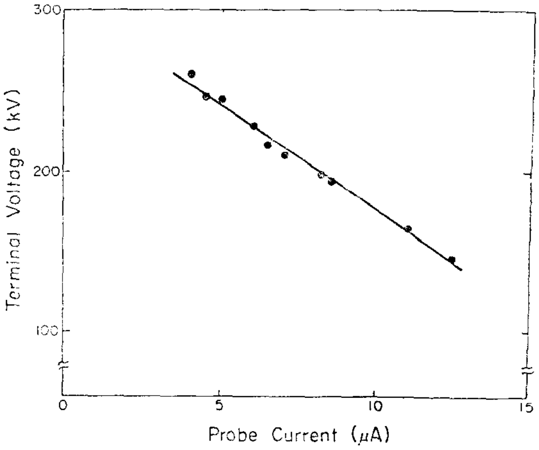

Fig. 6. Terminal Voltage as a Function of Probe Current.

low energy slit element, the grid voltage increases to increase probe current drawn from the high voltage terminal and then to decrease the terminal voltage, and vice versa. It is shown in Fig. 5 that the probe current is drawn more easily when the distance between corona needle and the high voltage terminal shortens, and the ratio of variation of terminal voltage to that of grid voltage is about 20,000. When there is no load current except resistive current, the terminal voltage decreases in proportion to the probe current as shown in the Fig. 6.

The high voltage stabilization system was operated with the terminal voltage of 247.3kV. The terminal voltage was monitored by the generating voltmeter and the result is shown in Fig. 7. When terminal voltage is stabilized, the fluctuation of the terminal voltage is too small to be measured, but that of high frequency over 10Hz remains with very small magnitude.

This fluctuation can be eliminated by introduction of capacitive liner method. The slit current was measured as a function of the position of slit element and fitted result is shown in Fig. 8. Using this result, the beam energy stability was determined. For the slit current variation (ΔI) of $\pm 2nA$ for $I=50nA$, the variation of the position of the slit element (Δe), which is equal to that of beam position, is ± 0.01mm. From this value the energy stability is determined by

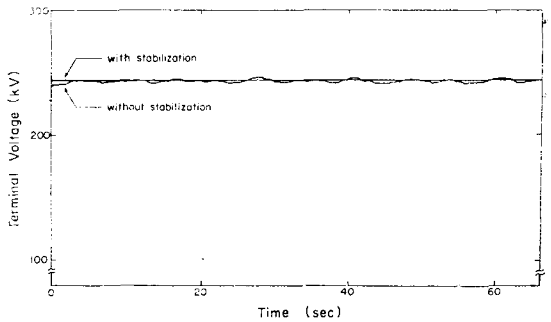

Fig. 7. The Effect of High Voltage Stabilization.

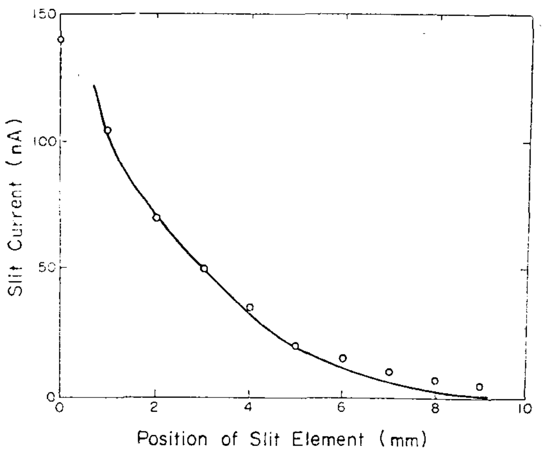

Fig. 8. Slit Current as a Function of the Position of Slit Element.

use of Eq. 5. For the analyzing magnet and the differential slit, the arc length S_s is equal to 824.7mm. Then, the energy stability becomes $\Delta E/E=2.44\times 10^{-4}$. For the proton beam with the energy of 508.9keV, the energy spread is ± 124.2eV and stabilization factor is equal to 29.4.

VI. Conclusion

Operational characteristics of beam handling system and ion optical components were examined and optimized. Thus, for the extracted H^- beam current of $3\mu A$, the accelerated proton beam current of $350nA$ can be easily obtained. This is considered to be sufficient beam intensity for PIXE analysis which has been carried out after the success of high voltage stabilization.

A high voltage stabilization system using grid controlled triode (6BK4) was set up and its operational characteristics were examined and optimized. Under the optimum condition, energy stability is found to be $\Delta E/E=2.44\times 10^{-4}$ and stabilization factor is 29.4 at terminal voltage of 247.3kV. Residual fluctuation with high frequency over 10Hz is still apparent. In order to eliminate this fluctuation, capacitive liner method must be introduced. It is planned to operate the high voltage stabilization system at the terminal voltage of MV range using the results of this research.

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