© 1967 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

TERMINAL VOLTAGE FLUCTUATIONS OF AN FN TANDEM VAN DE GRAAFF ACCELERATOR*

H. Fauska, J.S. Heagney, T.J. Morgan, and F.H. Schmidt
University of Washington, Seattle, Washington

Introduction

The terminal potential of the University of Washington FN Tandem Van de Graaff accelerator fluctuates by 500 to 1000 volts, even under the best of operating conditions. The pattern of the fluctuations is periodic at the frequency of the belt cycle; the dominant frequency spectrum extends from the belt frequency, which is about 2.4 Hz, to about 30-40 Hz. The voltage pattern, which is quite complicated, repeats over and over each belt cycle in a remarkably faithful manner. Although the voltage pattern is different when the corona regulator is in proper operation, it too repeats in a carbon-copy fashion.

The repetitive character of the fluctuations clearly indicates that the cause lies in inhomogeneities of the belt. In what follows below evidence is presented indicating that the inhomogeneities probably arise from the manner in which the rubber-impregnating compound on the belt is cured. A simple method is suggested for reducing the effects of these inhomogeneities. Finally, it is shown that charge spreads out on the belt after deposition, but that it spreads out non-uniformly, much as water might flow out non-uniformly over an uneven horizontal surface. This finding rules out the possibility of devising an analog memory-type regulator[1] to cancel out the fluctuations.

Effects on Accelerated Beam

Since a terminal voltage fluctuation of one kV means a proton beam energy fluctuation of only 2 keV, one might conclude that the effect is too small to be of importance. However, this is not the case. At 10 MeV, the dispersion of the beam analyzing magnet causes a motion of about 0.001 inch per 250 eV. Thus a terminal fluctuation of 1 kV moves the proton beam about 0.008 inches. With a typical operating image slit width of approximately 0.020 inches, the beam intensity fluctuates from 30 to 50% due to the terminal potential variations.

For experiments involving coincidences between two nuclear radiations, the accidental rates are proportional to the square of the beam intensity. Thus, a fluctuating beam produces a higher accidental rate than a steady beam of the same average intensity. Moreover, one cannot calculate the accidentals from known resolving times unless the exact beam-time pattern is known.

The side-to-side motion of the beam within the confines of the image slit is disturbing to precise scattering experiments, especially if the beam switching system following the image slits bends the beam in the same sense as does the analyzing magnet. For the University of Washington external beam facility, this effect virtually rules out the use of the 30° and 45° beam exits on one side of the switching magnet for precise experiments.

Also, recently there have been found very narrow nuclear analog resonances the widths of which are less than 1 keV.

Terminal Potential and Charge Current Fluctuations

A typical oscillogram of the terminal potential, as detected by the usual capacitive pickup electrodes, is shown in Fig. 1. Two belt periods are visible on the trace. The peak-to-peak fluctuation is ∿ 2.4 kV at a terminal potential of 4 MV.

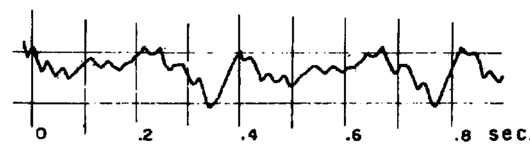

Figure 1. Oscillogram tracing of terminal potential. Note that the pattern repeats each belt cycle. Peak-to-peak fluctuation is ∿ 2.4 kV.

By means of a shorting rod which can be inserted through a seal in the wall of the Van de Graaff pressure vessel, we have studied the current delivered to the terminal. A typical oscillogram is shown in Fig. 2. The charging current delivered to the belt was 100 μA. The peak-to-peak fluctuation is about 75 μA.

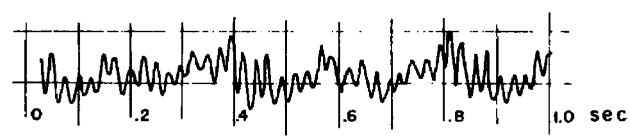

Figure 2. Oscillogram tracing of terminal current. Note that the pattern repeats each belt cycle. Belt charge current = 100 uA.

Although Fig. 1 and Fig. 2 do not demonstrate that the voltage fluctuations are correlated with the current, chiefly because these two oscillograms were taken at widely different times, we have verified that the expected correlation does exist. The voltage fluctuations are of course very heavily attenuated by the effective RC of the terminal.

We have also examined the momentum analyzed beam at the image slits of the customary analyzing magnet. The beam energy does fluctuate with the same pattern as the terminal potential, which leaves no doubt as to the real existence of the potential variations.

The oscillograms of Fig. 1 and Fig. 2 show frequencies extending from the belt frequency up to ∿ 60 Hz. Figure 2 especially shows a very prominent component containing 17 peaks per belt cycle, or a frequency of ∿ 40 Hz. We have observed that three different charging belts show almost exactly the same periodicity. This fact was not at first recognized, and only after examination of old oscilloscope photographs taken as a routine check on belt condition, did we find that a frequency corresponding closely to 17 peaks per belt length was imbedded in each belt. One belt was removed because the current fluctuations became excessive, even though the charge and discharge screens were in good condition and properly adjusted. The second belt was removed because of accidental damage. We have some, though not conclusive, evidence that belts gradually generate a larger and larger "17-peak" structure as they age or wear.

The "17-peak" structure is evidently caused by the method of curing the rubber impregnation applied to the belt during the manufacturing process. The "curing length" is 30 inches with about a 2-inch overlap at each end.[2] The average length of a belt is 454 inches. This gives very nearly 17 cure patterns in the length of the belt. An obvious remedy would be to develop a system for a uniform and continuous curing procedure, such as between rollers.

Alternatively, if the frequency of the inhomogeneities could be increased, say by a factor of two, the terminal ripple would be reduced by a factor of about two by the RC filtering action. The High Voltage Engineering Corporation has agreed to make us a belt with an effective curing length of 15 inches instead of 30 inches.

Effects Due to Corona Regulator System

The corona regulator produces a phase shift of very nearly 90° for frequencies above about 10 Hz. The effective resistance of the corona discharge at 5 MV and 100 μA corona current is 5×10^{10} ohms. With an assumed effective terminal capacitance of 100 pF, the phase shift between a driving voltage on the corona points and the terminal is very close to 90° at 10 Hz. A single voltage pulse at the terminal with a width less than 0.1 second appears approximately as a differentiated pulse when the regulator is in operation. Moreover, the regulator tends to hunt at a frequency of about 20 Hz. Nevertheless, if the gain of the regulator is not too high, the terminal potential is still a pattern which repeats, carbon-copy like, each belt cycle. The corona regulator can eliminate low frequency components, for example the belt frequency, but due to the 90° phase shift cannot eliminate the 40 Hz frequency due to the 17 peaks per belt cycle.

Charge Spread on the Belt

We constructed a circuit with which we could introduce either periodic or step function modulation of the belt charge current. Figure 3 shows the effect on the terminal current due to a step-function decrease in belt charge. Figure 3a shows the current pattern in the absence of the step, and Fig. 3b shows the current pattern with the step. The step occurs at the point marked, and is the voltage supplied by the belt charge circuit. That point on the belt reaches the terminal 200 ms later, and the average current is seen to begin to change. Figure 3c shows the approximate difference in terminal current between Figs. 3a and b. The sharp rise charge step has spread out to a gentle rise extending over about 70-80 ms, with a 90% decrease in 60 ms. Nevertheless, the basic pattern remains unaltered.

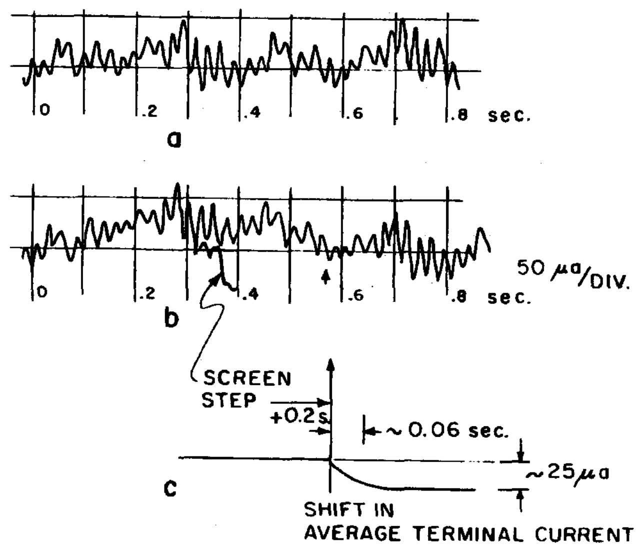

Figure 3. (a) Terminal current when belt charge current is constant. (b) Terminal current when a step decrease is applied to belt charge current. (c) Approximate difference between tract (a) and (b) showing how the charge spreads out between the base and terminal.

The above observation suggests that as charge is fed to the belt it spreads out as the belt moves toward the terminal, but it tends to concentrate in a particular pattern. Since the distance the charge spreads in the time of transit from the charge screen to the terminal is greater than the distance between the inhomogeneities in the belt, it is not possible to smooth out the charge inhomogeneities by feeding an appropriate signal to the charging circuit. This means that a regulator based upon an analog memory system utilizing a tape recorder[1] will not work, unless the conductivity of the belt is substantially reduced.

Miscellaneous Observations

The terminal current ripple pattern for a given belt changes only slowly with time. We have oscilloscope photographs taken two weeks apart which show almost exactly the same pattern. However, there is some evidence that the inhomogeneities of a given belt grow over a period of months.

If the charging and take-off screens are poorly adjusted, the current pattern does not repeat each belt cycle. Thus, improper screen adjustment can cause large instabilities in operation.

The so-called self charge generated on the belt when the impressed charging current is zero also exhibits a repeating pattern, but it is much smaller than the fluctuations with normal charging current. Thus, self-charge is not a cause of the fluctuations. With the tank at atmospheric pressure we studied the self-charge with and without the terminal pick-off screen in place and found it unchanged for the two arrangements. This suggests that self-charge is mainly on the inside of the belt.

The terminal current ripple depends upon the humidity of the tank gas and upon the length of time the belt has been dried by the tank gas. It is worse under humid conditions. This observation supports the thesis that the fluctuations are due to a balance between the rate at which charge spreads out after being deposited on the belt and the inhomogeneities of the belt. The charge current is maintained constant by the charging supply. The non-uniformity of the current reaching the terminal must therefore be produced during the belt transit from the base to the terminal.

We have also studied the voltage pattern supplied to the belt by the constant current charging supply. This voltage exhibits a repeating pattern which shows definite correlation with the current pattern received at the terminal, displaced by 200 ms.

Acknowledgments

We wish to thank I. Halpern and J.G. Cramer for a number of helpful suggestions, and to thank J. Shaw and other members of the High Voltage Engineering Corporation for valuable discussions and cooperation.

References

* Supported in part by the U.S. Atomic Energy Commission.

1. J.S. Heagney, T.J. Morgan, and F.H. Schmidt, Annual Report, Nuclear Physics Laboratory, University of Washington, p. 98 (1966).

2. Jacques Shaw, High Voltage Engineering Corporation, private communication.