# STABILIZED DC POWER SUPPLIES FOR BEAM INJECTION INTO ORBITAL ACCELERATORS

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This paper deals with design considerations for the 800 kV power supply of the preaccelerator for the 12.5 BeV Zero Gradient Synchrotron in operation at Argonne National Laboratory.

Large orbital accelerators require the injection of pre-accelerated particles. Electrostatic or Cockcroft-Walton generators and linear accelerators are normally used for the initial stages of acceleration. This paper describes the 800 kV power supply of the pre-accelerator for the 12.5 BeV Zero Gradient Synchrotron in operation at the Argonne National Laboratory, Illinois.

The power supply had to meet the following maximum requirements :

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| DC Output voltage | 800 kV |
| Rated current, continuously | 8 mA |
| Pulse current | 200 mA |
| Pulse duration | 2 msec |
| Repetition rate | 10 pulses per second |
| Overall stability | $1 \times 10^{-3}$ during and between the pulses. |

Since high current pulses of up to 200 mA and up to 2 millisecond duration were required, the large current capability of the symmetrical cascade generator was of particular use. In another article published in these Proceedings, reference is made to the circuit diagram and the particular features of the symmetrical cascade generator [1,2]. It consists of two standard Cockcroft-Walton circuits connected in parallel with only one common column of smoothing capacitors. As explained in the other article, the symmetrical cascade rectifier does not produce any capacitive voltage ripple. Moreover, the load-dependent voltage ripple and the total voltage drop are very small in comparison with the standard circuit. These features facilitate the stabilization of the dc output voltage even under the severe conditions of pulsed load. The electrical diagram of the complete installation is shown in figure 1.

The cascade generator consists of 4 stages of 200 kV each. All smoothing and coupling capacitors have capacitances of 0.032 μF each, with the exception of the coupling capacitors of the bottom stage which are rated at 0.064 μF each. The bottom coupling capacitors have to withstand only half the rated voltage of the other capacitors. High voltage selenium rectifiers with a rated current of 10 mA were used. These rectifiers are superior to vacuum tubes in that they do not require filament supplies at high potentials, thus insulating transformers or auxiliary generators can be avoided. As compared to silicon diodes, selenium rectifiers can be made of a more compact and simpler design. No shunt capacitors or series-resistors are required to provide a uniform voltage distribution across the series-connection of diodes, nor are selenium rectifiers as sensitive to overvoltages and over-currents as are silicon diodes [3].

The cascade rectifier is operated at 480 cps and fed by two high voltage transformers with a secondary voltage of 90 kV each. The transformers are energized from a stabilized frequency converter set. A filter stack consisting of 4 filter capacitors of 0.032 μF each and a filter resistor of 500 kohms is connected to the high voltage terminal of the cascade rectifier in order to reduce the residual voltage ripple. Resistors are connected between the respective stages of the smoothing and filter columns in order to provide a uniform dc voltage distribution along the filter stack.

The power supply is connected to the accelerator or high voltage structure through a protective resistor of 50 kohms. The accelerator structure includes the ion source and auxiliary electrical equipment in a large high voltage terminal made of highly polished aluminum, as seen in figure 2. The high voltage terminal is resting on three insulating supports, one of which is the measuring potentiometer for the stabilization of the accelerating voltage. The ion source is energized from an ac generator of 400 cps, which is driven through an insulating shaft by a motor on ground potential. The output power of the generator is 15 kW. The motor generator set is mounted on a freestanding tripod of steel, which also supports the insulating cylinder and drive shaft. There are no rigid connections between the driving column and the high voltage structure in order to avoid vibrations.

The measuring unit is designed as an ohmic-capacitive potentiometer. Its resistance is $4 \times 10^8$ ohms, and the total parallel capacitance is 1000 µµF. An oil circulating system and cooler are provided for the heat dissipation of the measuring potentiometer, since the total power losses in the metering resistor amount to 1600 watts at a rated current of 2 mA at 800 kV. The measuring potentiometer plays an important role in the stabilization circuit. It must be emphasized that a pure ohmic potentiometer would be too slow for the requirements of pulse stabilization.

If the current pulse of 200 mA is drawn from the cascade rectifier, at first the capacitors of the measuring potentiometer will be partially discharged, and a voltage drop will appear across the protective resistor of 50 kohms. The operating frequency of 480 cps is too low to supply further energy from the high voltage transformers through the capacitors. For this reason, the filter capacitors will also be partially discharged. It is easy to calculate that the total capacitance of the installation is not sufficiently large to keep the dc output voltage within the required limits of 0.1 percent during the pulse duration.

For this reason , the output voltage is stabilized by means of a bouncer rectifier which is inserted between the bottom center point of the symmetrical cascade generator and ground. The high voltage triode in the bouncer rectifier has to meet various severe requirements. It must be able to supply the full pulse current of 200 mA and to compensate for the voltage drop of the cascade rectifier during the pulse which may be as high as 50 kV. Moreover, the risetime of the voltage pulse from the bouncer rectifier must be short enough in order to follow the short risetime of the load pulses which is in the order of microseconds.

The fine or fast stabilization in the high voltage circuit operates in the following way. The secondary voltage of the measuring potentiometer is compared with an adjustable reference voltage source. The error signals, i.e. the deviations between the secondary voltage and the reference source, are amplified in ac and dc amplifiers and applied to the grid of the high voltage triode in the bouncer rectifier.

The response times of the ac amplifiers and of the bouncer rectifier can be made sufficiently short. Particular attention, however, must be paid to the performance of the measuring resistor in the stabilization loop. Due to the natural stray capacitances from the resistor column to ground, high ohmic measuring potentiometers are always rather slow. Figure 3 shows the secondary voltage rise of a pure ohmic potentiometer, if a unit step voltage is applied to the high voltage terminal. The measuring resistance R and the stray capacitance $C_s$ are represented by the iterative network shown in figure 3, where $R = n\,R'$ and $C_s = n\,C_s'$. $R'$ and $C_s'$ are the resistance and stray capacitance per link of the network. With a high number of links n the stray capacitance becomes uniformly distributed. If the unit step voltage is applied to the network, the secondary voltage $V_2$ is given by the series

$$\frac{V_2(\tau)}{V_2(\infty)} = 1 + 2 \sum_{k=1}^{n} \left( (-1)^k \, e^{-k^2 \pi^2 \tau} \right) \qquad (1)$$

where $\tau = \dfrac{t}{RC_s}$

This result was obtained by applying the theory of iterative networks and Laplace's transformation [4].

The time axis is expressed in fractions of the time constant of the potentiometer which is $RC_s$. Assuming a total stray capacitance of 100 µµF for the 800 kV metering resistor, the time scale would become $t = 40\,\tau$ in milliseconds. It is evident from the curve in figure 3 that a pure ohmic metering resistor cannot be used for stabilization purposes in the millisecond range. The frequency response can be greatly improved by connecting capacitors in parallel to the measuring units. From figure 4 it is apparent that steep rises of the secondary voltage can be obtained if the ratio between the total parallel capacitance $C_p$ and the stray capacitance $C_s$ is made $C_p/C_s \geqq 1$. These curves were computed from the behaviour of the iterative network shown in figure 4. The relative rise of the secondary voltage is now given by the series

$$\frac{V_2(\tau)}{V_2(\infty)} = 1+2\sum_{k=1}^{n}(-1)^k \frac{e^{-k^2\pi^2\tau/(1+k^2\pi^2 C_p/C_s)}}{1+k^2\pi^2 C_p/C_s} \tag{2}$$

The ratio of the parallel capacitance $C_p = 1000\ \mu\mu F$ to the stray capacitance $C_s = 100\ \mu\mu F$ is $C_p / C_s = 10$. The uppermost curve of figure 4 applies. With this ratio of 10 the secondary voltage will immediately rise to more than 98 percent of the final value.

Practical experience has shown that the stabilization circuit is effective and fast enough in order to keep the dc output voltage within the permissible limits of 0.1 percent.

A coarse stabilization is provided at the frequency converter set in order to compensate for the slow fluctuations of the mains supply voltage.

The particular problems involved in the design and construction of a stabilized high voltage dc power supply are created neither by high voltage techniques nor electronics, but by the combination of these two diametrically opposed fields of electrical engineering. It is the simultaneous operation of two different kinds of electrical equipment, one operated in the megavolt range and the other in the millivolt range, that are causing problems in achieving both high voltage and high stability at the same time.

References

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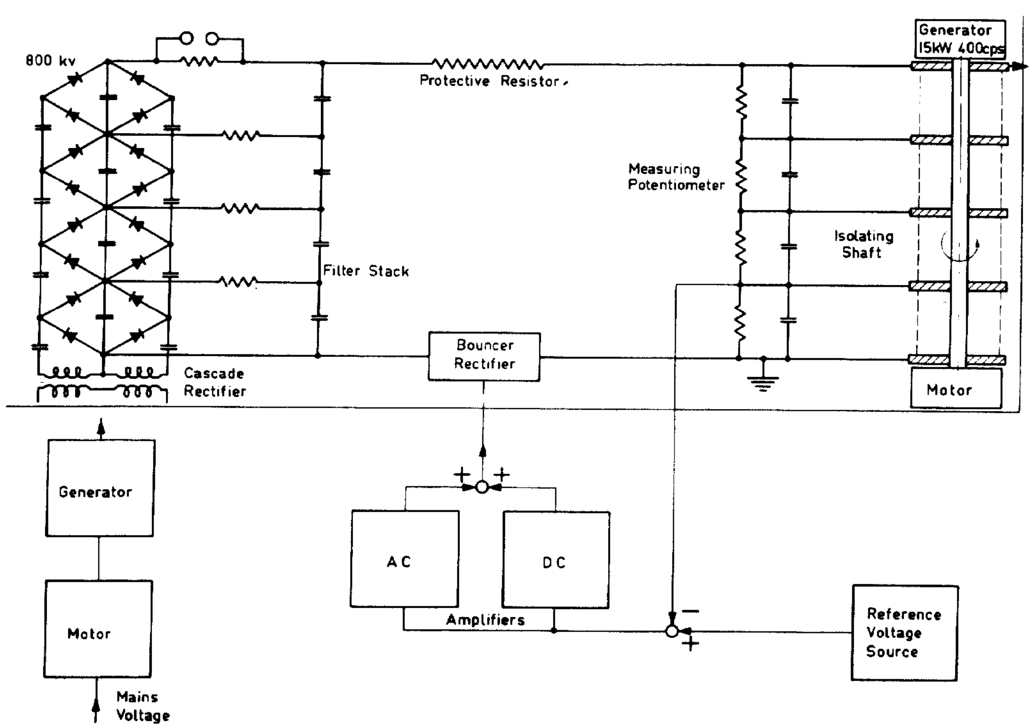


Fig. 1. Block diagram of the injector power supply.

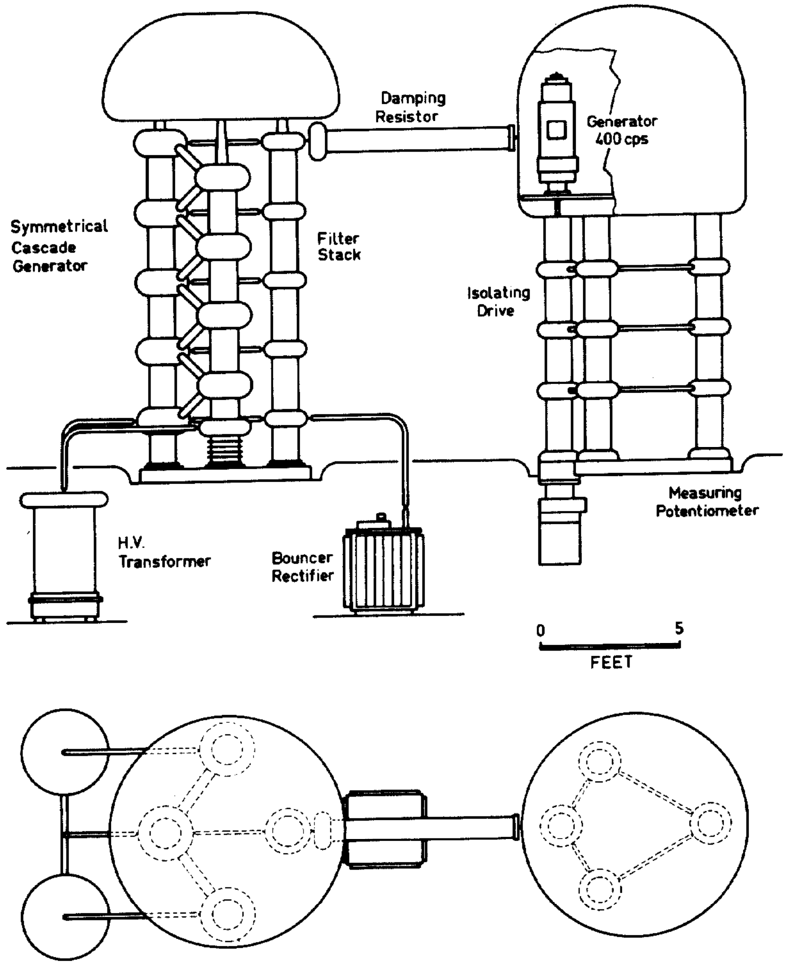


Fig. 2. Mechanical layout of the injector power supply.

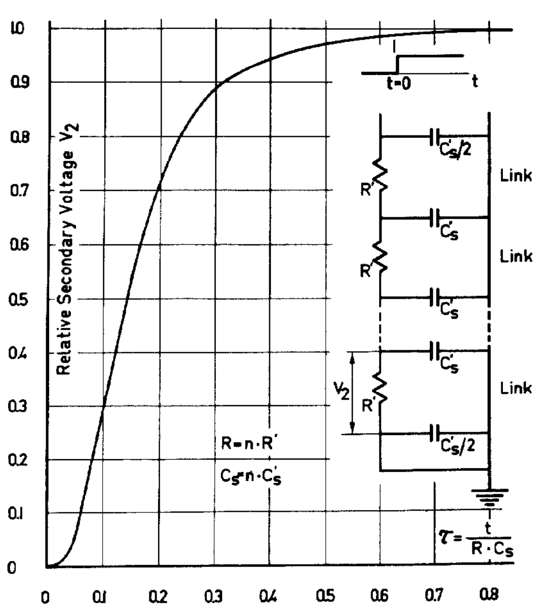


Fig. 3. Response of an ohmic potentiometer under the influence of stray capacitances.

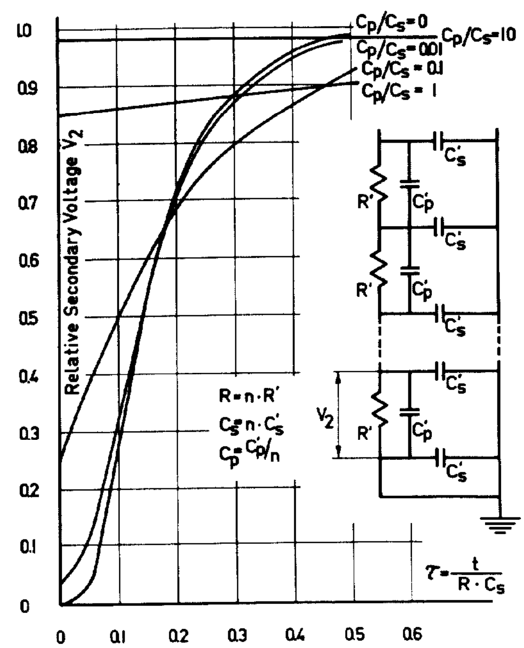


Fig. 4. Response of an ohmic-capacitive potentiometer under the influence of stray capacitances.