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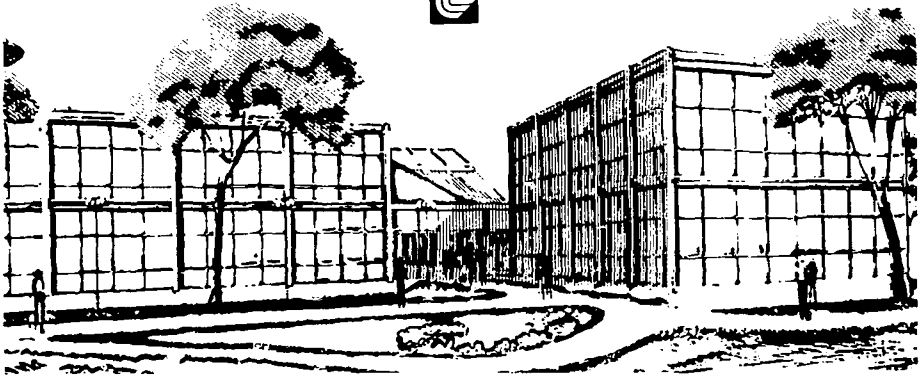

MODULATOR CHARGING SYSTEM UPGRADE FOR A 5-MeV ELECTRON ACCELERATOR*

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SUMMARY

The Lawrence Livermore Laboratory is currently constructing a new linear induction accelerator with a higher beam current than the Astron[1] accelerator. The new accelerator, called the Experimental Test Accelerator (ETA) will be a 5-MeV, 10-kA accelerator with a pulse width of 50-ns. Like the Astron, the principle of magnetic induction is used to obtain a linear accelerator. The modular accelerating cavities form essentially a 1:1 transformer and the change in flux in the ferrite core induces an axial electric field for the acceleration of electrons.

Since the total energy storage for the ETA is much greater than the requirement for Astron, the power system, the capacitor bank and the modulator charging system all had to be modified to provide an overall regulation of .1%. This strict regulation of the charging voltage is necessary for pulse-to-pulse repeatability.

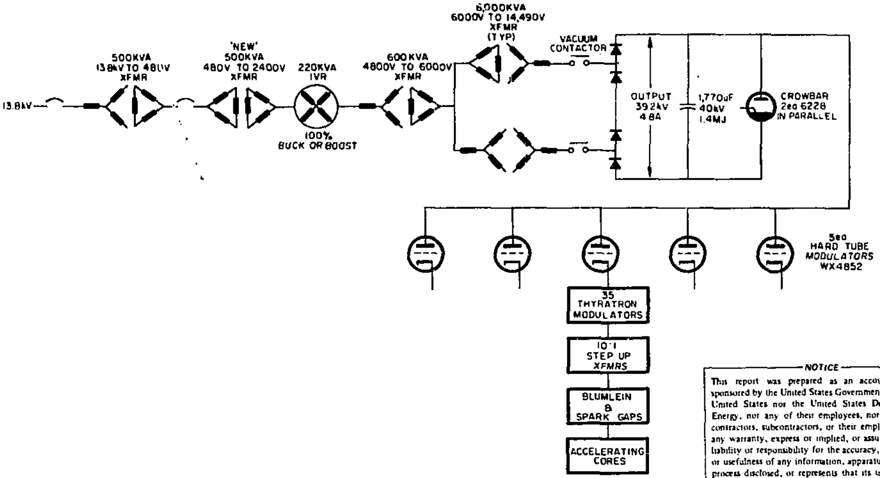

FIG. 1 ONE LINE DIAGRAM OF MODIFIED CHARGING SYSTEM

Hard Tube Modulator

The pulse forming network for the accelerating cavity consists of a Blumlein which is charged to 250-kV by an off resonance step-up transformer from a 3.3-μf, 25-kV capacitor. A total of one hundred and seventy-five capacitors are required to provide the energy storage for the burst mode capability and desired energy out. Fig. 1 is a system schematic.

With this large capacitance, 578-μf, the command resonance charge mode of charging would have resulted in an excessive amount of current and power dissipation in the WX4852 output tube. The constant current mode of charging was chosen using a voltage ramp with a duration of 250-ms. The resultant current for a 250-ms charge time is:

$$I = C\,\frac{\Delta V}{\Delta T} + 578 \times 10^{-6} \times \frac{25 \times 10^{3}}{25 \times 10^{-2}} = 57.8 \text{ Amps} \qquad (1)$$

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[1] Christofilos, N.C. et al. "High Current Linear Induction Accelerator for Electrons." RSI Vol. 35, No. 7 886-890, July 1964.

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The hard tube modulators are shown in Fig. 2, and Fig. 3 is the schematic. Each modulator charges 35 of the 3.3-μf capacitors to 22-kV. Usual pulse rates will vary from one to five pps, however, much higher rates are required for some experiments. In such cases the accelerator is operated in the burst mode with the average rate held to the cw rate of 5 pps or less.

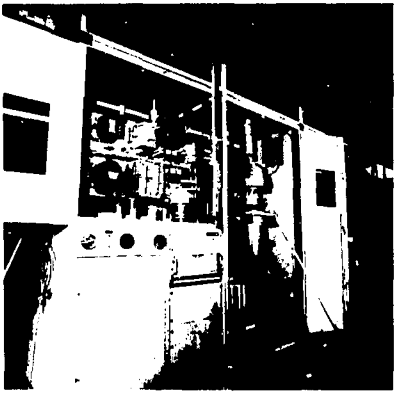


FIG. 2 FRONT VIEW OF HARD TUBE MODULATOR

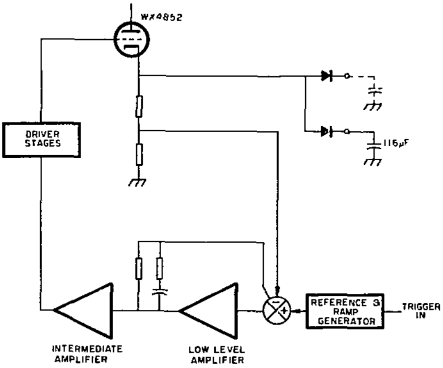


FIG. 3 CONSTANT CURRENT MODULATOR SCHEMATIC

Although five modulators are available for normal operation, it was decided to have the full system capability with any three of the modulators operational. This would result in a maximum current requirement of 23 amps from any one modulator. A maximum tube drop of 5-kV would be required for good voltage regulation; meaning the capacitor bank could be run at 30-kV, resulting in a peak power dissipation of 690-kW across the output tube. One advantage of the lower current required is that it is no longer necessary to drive the grid of the WX4852 positive to obtain the desired output current.

The basic modulator design is the same as for the Astron accelerator, the mode of the operation, output resonant charge circuit, and the low level reference system have been modified for constant current operation. Each modulator charges 116-μf worth of capacitors, thus providing one of five pulses in a burst operation. The resonant charging circuit has been removed and dual output diodes provide charging and isolation between two sequential pulses of the burst. The use of the dual output diode allows the removal of one or two modulators from the system without affecting overall accelerator operation. The 250-ms charge time was chosen so that the peak power dissipated would not exceed ratings in the anode of the 4852. Peak power, of course, occurs at the start of the cycle.

Reference and Driver Stages

The actual constant current in the output is obtained by calling for a voltage ramp from the ramp generator which is shown in Fig. 4. The time duration of the ramp is controlled by counting down from a 10-mHz clock and is adjustable from 100-ms to 500-ms by setting the time on digital thumbwheel switches. The output of the modulator is compared to this ramp in the low level amplifier, and the error signal is amplified by the intermediate amplifier and driver stages. It is then fed to the grid of the final tube in a closed loop system. Note that since the modulators are not operated in the 1-kHz charging mode, the full closed loop gain is available for the regulated output. In our system, with a six Db/octive roll-off, the loop gain at 250-ms charge time is about ten to twenty times better than the resonant charge system of the Astron. The loop gain could be further increased at the low frequency end at a very nominal cost, should it become necessary. The ramp voltage and the output voltage are *shown in Fig. 5.*

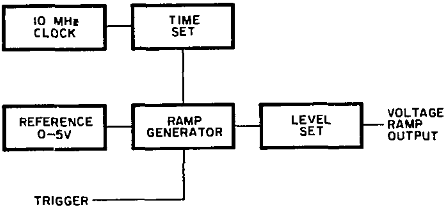
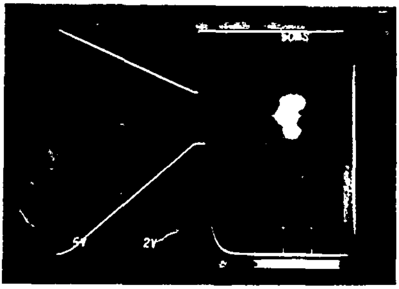


FIG. 4 BLOCK DIAGRAM OF RAMP GENERATOR



TOP REFERENCE VOLTAGE 2 V/cm
BOTTOM MODULATOR OUTPUT 5 kV/cm
VERTICAL 50 ms/cm

FIG. 5

Power System and Capacitor Bank

With an output requirement of 22-kV, and allowing a tube drop of 5-kV, the power supply would have to be operated at a minimum of 27-kV. To supply the full voltage at 57.8-A would have meant a costly modification to the power system. A compromise was reached where the ratio of peak-to-average power requirements were satisfied by enlarging both the primary capacitor bank energy storage, and the power input. The original bank was 770-μf and 570-kJ. By rearranging the configuration of the bank, we were able to connect it so the total capacitance is now 1770-μf at 40-kV for an energy storage of 1.4-MJ (Fig. 6).

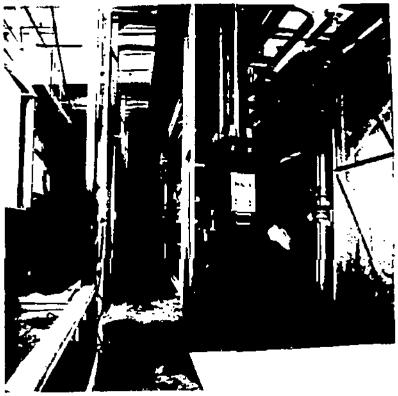


FIG. 6 1.4 MEGAJOULE CAPACITOR BANK

When running in the burst mode, the current from the power supply will be 57.8-A, with an input current of 8-A. The capacitor bank voltage will be:

$$\Delta V = \left(\frac{I_{out} - I_{in}}{C}\right) \Delta T \qquad \Delta T = .25 \text{ sec} \tag{2}$$

$$\Delta V = \left(\frac{57.8 - 8}{1770 \times 10^{-6}}\right) .25 = 7.03 \text{ kV} \tag{3}$$

The capacitor bank must be charged to a total of:

$$V_{bank} = V_{out} + V_{tube} + V_{saq} = 22 \text{ kV} + 5 \text{ kV} + 7 \text{ kV} = 34 \text{ kV} \tag{4}$$

Since the capacitor bank is rated at 40-kV and has been run at this level this should present no problem. The modulators have all been tested into a dummy load that very closely approximates the system. The charging current for a single modulator was measured at 11.2 amps, vs. 11.5 amps calculated, with an output voltage from the modulator of 22-kV and 34-kV on the bank.

Power Supply Primary Equipment

The original Astron power supply primary equipment consisted of a 20 megawatt motor-alternator for high power operation and a second circuit that could be switched to replace the motor alternator for low power operation. The low power circuit was an after thought to save wear on the high maintenance motor alternator and was assembled from components that were on hand. Because of this, some components were rated greater than others and the output was limited to about 125-kW. When the Astron accelerator was dismantled, the motor-alternator was also removed thereby limiting the output of the 15 megawatt transformer-rectifier to 125-kW.

It was decided to use this power supply for the new 5-MeV Electron Accelerator and ways were investigated to increase the output above 125-kW. Four options were considered to increase the output of the power supply by replacing the limiting components. Of course, all components could be replaced and a full 15 megawatts could be obtained, but this was not needed for the accelerator nor would the budget allow it. It was decided to replace the limiting 150-KVA, 480 to 2400 volt, transformer with a 500-KVA unit to give an output of 188-kW. A 500-KVA transformer was chosen so it would not be the limiting item if subsequent options were to be installed. 188-kW appeared to be a satisfactory starting point for the accelerator and if increased power is needed the other limiting components could be replaced, giving 474-kW. Fig. 1 shows a one-line diagram of the modified power supply.

CONCLUSION

In accelerators where a high degree of regulation is required in the electronics for beam quality, a series modulator is invariably used to provide that degree of regulation. In the Astron accelerator, the power and regulation during a beam burst was provided by the modulators and parallel systems were not necessary. When the beam power during a burst becomes very large, the modulator cost and complexity become excessive. In the ETA it was decided to reduce the modulator power requirements by charging between bursts and sequentially firing parallel capacitors to obtain the high rep rate. For example, the average ETA power during a burst is:

$$P_w = \left(5 \times 10^6\right)\left(10^4\right) \times \frac{50 \; 10^{-9}}{.5 \; 10^{-3}} = 5 \text{ megawatts} \tag{5}$$

Because of power losses in compensating networks, charging transformer, switch chassis and modulators, the overall input power requirements are more like 25-50 MW. This would have meant a large and very costly modulator development and primary power supply changes. For higher rep-rate requirements the accelerator power during the burst is even greater, which makes the primary power supply and modulator requirements excessive, and one has to resort to an intermediate energy storage to provide the burst energy.

REFERENCES

1. Smith, Mark E., "Recent Changes in the Astron Fast Pulsing System," 4th Symposium on Engineering Problems of Fusion Research.