THE RF SYSTEM FOR THE AGS 200-MEV LINAC*

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Introduction

A new injector for the AGS will be built with a design output current of 100 mA at 200 MeV. A prototype rf system for this linac is being built as a basis for final design. A description of this system is given below.

System Configuration

The 200-MeV linac for the AGS Conversion Program will use eight 200-Mc cavities. The rf power required by each cavity varies between one and five megawatts depending on the amount of beam loading. All eight cavities are to be powered by separate identical rf amplifier systems sharing a common frequency and timing source.

The design of eight identical systems is an advantage because of the savings in engineering costs and the possibility of having a complete working spare system. A block diagram of one rf system is shown in Fig. 1. The components are located in boxes exactly as in the block diagram. Each box is a complete package with its own control circuits, cooling, power distribution and monitoring devices.

Each unit can be easily removed and replaced with a pretested spare. This permits time-consuming repairs and updating modifications to be done without using machine downtime.

A unit can be thought of as a rather large printed circuit card, to be extracted and plugged into a test unit for repairs. The connecting plug on this card is in the form of water-cooling lines, electrical power, control lines and video signal cables.

By keeping the number of interconnections small, it is felt that "pulling a unit," instead of repairing or modifying it in place, can be practical.

Each module is about 4 × 12 ft × 8 ft high and is easily removed with an overhead crane or a specially designed rolling cart.

All control signals leaving a module are at low voltage dc. Direct intermixing of relay, switch, light bulb, techniques with computer-type data logging and control techniques is possible. Each rf system can be operated from its own local control station. This allows installation, debugging and repairs of each system to be done without conflicting with operation in other parts of the linac.

The Circuits

The rf amplifiers are of conventional coaxial cavity construction. Monitoring of all electrode parameters as well as interstage power and VSWR indications are made available. Prototypes of all amplifiers have been tested at this time. Duplicates of the driver stages are being considered for buncher and debuncher drive service. Each stage is to be run at saturation drive conditions to minimize phase and amplitude jitter in the rf output. The RCA 7835 output stage will be reviewed elsewhere.[1]

The charge control amplifier, Fig. 2., is a high-speed voltage/current regulator on the output of the main plate power supply. Since the AGS pulsing rate is determined by the induction motor and flywheel combination which provides stored energy to the AGS magnets, the linac operates at a submultiple of the motor slip speed and is not synchronized with the power line frequency. This would cause the ripple in any linac power supplies to show up as pulse-to-pulse amplitude jitter.

The control of capacitor bank recharge current eliminates this problem and provides the isolation to extinguish the crowbar by controlling the recharge current.

Another function of the charge control system is the reduction of rf system power demand variations. If an inductive charging system were used the peak current would be given by

$$\frac{\pi}{2}\,\frac{C\Delta V}{T} \le I_{max} \le 1.9\,\frac{C\Delta V}{T}$$

for high or low Q circuits respectively. This means that each linac module would draw peak currents of between 8.25 and 10.0 amperes for 10% voltage droop on a 35 μF capacitor bank. This amounts to a power variation of 3 to 4 megawatts during the recharge pulse.

Using the charge control amplifier to allow charging at nearly constant current for the full rf interpulse period, the peak current can be significantly reduced. This not only lowers the power variations presented to the utility lines but eases the burden of local instrumentation regulation systems.

With this system the capacitor bank voltage can be changed on a pulse-to-pulse basis allowing preprogrammed variations in pulse width, rate and amplitude of the rf output power. This allows linac machine studies to be made during AGS interpulse intervals with complete freedom. This system will allow complete recovery from a crowbar

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without missing a pulse at the highest AGS repetition rate.

The recharge information is transmitted to the series control tube by a pulse width modulated optical telemetering system.

The charge control system thus serves to program and regulate the capacitor voltage with flexibility not available in inductive charging systems, while minimizing the power variations which they cause. Since the charge control tube performs these functions by acting as a variable resistor the question of the charging efficiency of this system versus the known high efficiency of inductive charging was investigated.

The charging efficiency of the present system can be calculated in a straightforward manner. Referring to the conventional dc power supply - capacitor configuration shown in Fig. 3, it is seen that the energy delivered by the power supply is

$$W_{PS} = E_{PS} \int i \, dt$$

while the energy increase of the capacitor is given by

$$W_{CAP} = \frac{1}{2} C \left(E_2^2 - E_1^2\right) .$$

where E_1 and E_2 are the voltages on the capacitor at the start and end of the recharge, and E_{PS} is the power supply voltage. This may be used to calculate the charging efficiency for any initial and final capacitor voltages.

The ratio of energy delivered to the capacitor bank to energy extracted from the power supply is

$$\frac{W_{CAP}}{W_{PS}} = \frac{E_1 + E_2}{2 \, E_{PS}}$$

A charge from zero to full power supply voltage results in an efficiency of 50%, while a recharge after a 10% droop in capacitor bank voltage results in efficiencies of 95%. It is interesting to note that the series elements in the charging loop do not affect the efficiency but only the time and peak currents required.

The added power necessary for filaments is a small price to pay for the added flexibility of control.

The modulator, Fig. 4, has been designed to permit high gain, fast servo loop response for control of cavity gradient during beam loading. Separate routes have been used to transmit on-off information and amplitude control to the floating deck of the modulator. The on-off information is transmitted from a solid state infrared diode light source through fiber optics to a diode detector and amplifier. Signals of 50 nanoseconds rise time are available for modulator turn-on and turn-off. The amplitude control is electron-coupled by a grounded cathode high-gain triode to a constant current output stage driver tetrode. The high-gain triode and its transistor driver are the only stages of voltage gain in the system, thus allowing high gain fast response to be achieved. Modulator slewing rates of 25 kV per microsecond are intended to compensate for the 2 to 1 change in rf power called for during beam loading.

The capacitor bank of 40 μF at 60 kV allows efficient use of power by reducing the sag during a pulse. Normal sparking in the output rf circuitry will be stopped by turning the modulator off. This is backed up by an ignitron crowbar across the capacitor bank. Fault clearing time can be kept to less than one microsecond.

Conclusion

The complete system described is presently under construction and is expected to be in operation shortly.

Acknowledgment

The authors wish to acknowledge the work of R.F. Lankshear in the design of much of the system.

Reference

1. J. Keane, LASL Linac Conference, October, 1966, p. 183.

DISCUSSION

J. F. SHEEHAN, BNL

FREYMAN, LASL: On that last slide, would you put it back on for a second, please?

SHEEHAN: Could we have Slide No. 4 again, please?

FREYMAN: I didn't see a connection from the plate to the grid of the switch tubes on the DP-15. I don't understand how you get the signal from the plate of the DP-15 to the grids of the switch tube.

SHEEHAN: Let me consider the two power supplies as simply biasing arrangements; or let me draw a line through them and say that this just changes the dc potential. The DP-15 is pulling down on the grid of the 4CW10,000, which is trying to run as a constant-current source. If I look at all three tubes in series -- forgetting about the current that's delivered to the output load, the switch tubes, the 4CW10,000, and the DP-15 running in series - the 4CW10,000 wants to make the upper two tubes run constant current. Now my DP-15 is sitting with a constant current plate supply, so I can drive its grid with a voltage, and the plate-voltage signal looks simply like input times μ. It's kind of hard to figure the current path. The cutoff current through the grids of the tube must pass down through the DP-15. One of the advantages of this is that, for downward modulation, instead of wasting this power on a swamping resistor across the grids of the output stage, I can now downward modulate simply by dragging the grids of the output tubes down to ground through the DP-15. I should mention that a scheme very close to this is being used at the HILAC at Berkeley.

FREYMAN: What is your response time?

SHEEHAN: I haven't got the unit tested that far yet. I'm hoping for a slew rate of 25 kV/μsec.

HAGERMAN, LASL: How long do you think it will take to change out one of the major components - for example, the modulator or the final power amplifier?

SHEEHAN: I think you'll probably have to figure on something like an hour or two.

HAGERMAN: I mean, take out the whole box?

SHEEHAN: I think you can take the whole box out and put a new box in in ten minutes. I think that this is optimistic however, because you always have trouble with some pipe that starts leaking water or something, or something that doesn't fit right. But I think this is the advantage. It is the advantage that the accelerator people have when they have both options to make - repair or pull the unit out. Certainly, for small repairs, you'll go and make it in place. One of the other advantages is that now, with a separate unit, we can continually up-date the accelerator without having down-time. We can take the spare unit, build a new modulator, modify the modulator, and then during a half-hour down period, units can be swapped around.

HAGERMAN: This must mean that you are planning on a complete crane coverage in the equipment area.

SHEEHAN: Right. The building is designed for complete overhead crane coverage. There is no reason why the units couldn't be put on wheels just as well.

MILLER, SLAC: I was wondering what the advantages of your fiber optics are over conventional single light pipes since you seem to be taking only a single parameter across.

SHEEHAN: Where we are using two or three signals across in the case of the charge controllers, we actually have two fiber-optic systems: one which sets the control current as a pulse-width modulated signal; and the other sets the on-off command which says the capacitor bank is charged to the right voltage. The only advantages to the fiber optics, from what experience we've had with it, are that it's cheap, it's convenient, and we require no precise mechanical alignment between the transmitter and the receiver. Nothing magic about it; it could be done through an air gap.

CARNE, RHEL: Do you have any figures yet on the total cost of the system for the 200-MeV linac?

SHEEHAN: For the rf system alone? We have figures, but I don't remember what they are.

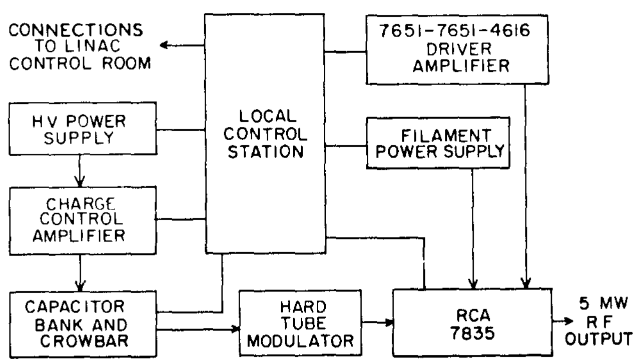

Fig. 1. RF system.

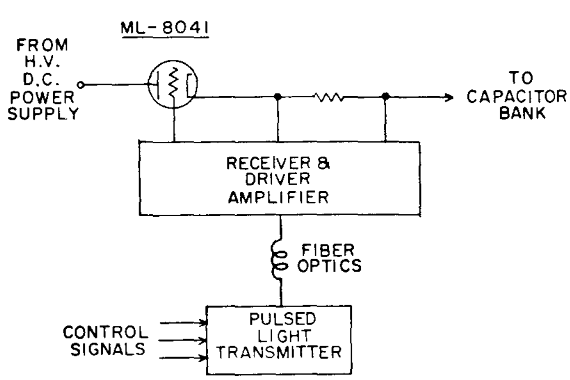

Fig. 2. Charge control amplifier.

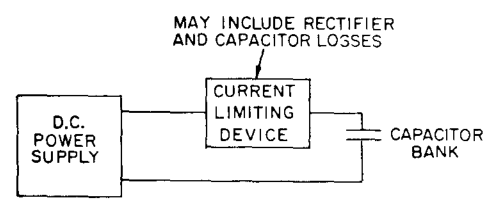

Fig. 3. Charging efficiency.

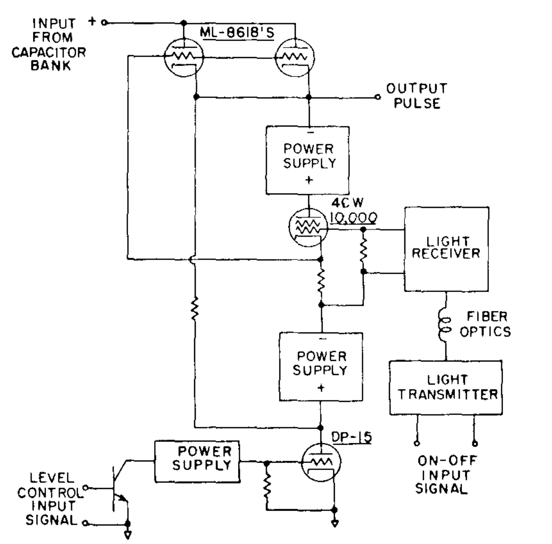

Fig. 4. Modulator.