LAMPF 200-MHz POWER SOURCES*

J. R. Faulkner and T. J. Boyd, Jr.
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Abstract

The Alvarez section of the proton linear accelerator for the Los Alamos Meson Physics Facility will require three 3 MW and one 300 kW, 200-MHz rf power sources. The power delivered to the accelerator tanks must be controlled over a dynamic range of approximately 30% while maintaining a field amplitude tolerance of ~ ±1.5% with a phase tolerance of ~ ±2°. The minimum rf duty factor (DF) requirement is 8.4% (for a 6% DF beam) with a design capability of 14.4% (12% beam). The moderate peak but high average power requirements have had a considerable impact on the design and engineering of the rf amplifier cavities and their peripheral circuitry. Several of these areas are discussed.

Summary

The first four accelerator cavities in the Los Alamos Meson Physics Facility will be of the Alvarez type, and will accelerate the proton beam from an injected energy of three quarters of an MeV up to 100-MeV. These structures will operate at a resonant frequency of 201.25 MHz and will receive their rf power from individual rf sources. The first Alvarez cavity will require approximately 300-kW peak power while each of the other cavities will require a nominal 3-MW peak power input. These rf power sources must be controlled over a dynamic range of approximately 30%, and the cavity field amplitude must be held within a tolerance of ±1.5%.

While the peak power required for the individual accelerator cavities is moderate, the design maximum of 12% beam DF brings about very high average power levels which have had a considerable impact upon the electrical and mechanical design of the rf power systems. Since the Alvarez cavities have a Q of about 50,000, the fill time necessary at 201.25 MHz is approximately 200 μsec. The LAMPF machine will be initially operated at 6% DF, 16.7-mA peak beam current, (1-mA average) with design capability for 12% DF, 8.3-mA peak beam (also 1-mA average). These beam DF's then dictate rf DF's of 8.4% and 14.4% respectively. Figure 1 lists the various design criteria for LAMPF.

System Description

The rf power systems which will be used to satisfy the requirements of the Alvarez cavities are shown in Figures 2 and 3.

The first Alvarez tank, requiring 350-kW peak rf power, will be driven by the system shown in Figure 2, which consists of two RCA Y1068 amplifiers operating in parallel, each supplying 175 kW of rf. These two amplifiers will be supplied from a common energy storage bank and a common high-voltage power supply and will be plate pulsed and plate modulated by a common series hard-tube modulator. The necessary phase control will be accomplished at low level prior to the Y1068 amplifier, while the rf amplitude will be controlled at high level via the series hard-tube modulator.

Alvarez tanks 2, 3, and 4 will be driven by the system illustrated in Figure 3, in which an RCA 7835 will supply approximately 3 MW of rf power. The 150 kW of rf drive required by the 7835 will be supplied by an RCA Y1068 amplifier. Both the 7835 and its driver will share a common high-voltage power supply and energy storage bank, but each will have its own series hard-tube modulator. The Y1068 driver will utilize an Eimac 4CW100,000D tetrode as a hard-tube modulator which will simply act as a plate pulser rather than a plate modulator. On the other hand the 7835 will be both plate pulsed and plate modulated by a pair of ITT 7560 triodes. As in the case above, the rf phase is controlled at low level and the amplitude control is performed at high level via the 7560 hard-tube modulator.

System Design Problem Areas

Now that the overall systems have been described, attention must be turned to the impact that the high average power requirements have had upon the actual hardware design.

The heart of the rf power system is the output tube itself; apparently the RCA 7835 triode is the only tube which can fulfill the system requirements. Its plate dissipation rating of 300 kW is marginal and serves to show the high premium which must be put on efficiency when working with the very high average power required by LAMPF. In order to obtain a full 3-MW output, the tube operates at roughly 30-kV plate potential with 200-A peak plate current. This, of course, represents 6-MW peak plate input. If a plate efficiency of only 50% were obtained at maximum DF of 14.4%, then the plate dissipation is 432 kW, which is well above maximum ratings for the tube. Assuming one were able to achieve a plate efficiency of 60%, then the plate dissipation is still 288 kW, just barely within the tube ratings. However, according to the theoretical calculations for the Alvarez cavities as shown in Figure 1, we do not require quite 3 MW. Reference to Figure 1 indicates that for a 12% DF 1-mA average beam, tank Number 3 requires a maximum of 2.59 MW. Using this as a maximum required power output, and considering the 300-kW maximum plate dissipation

* Work performed under the auspices of the U. S. Atomic Energy Commission.

rating for the 7835, a plate efficiency of at least 55.5% must be achieved to stay within the tube ratings.

The 7835 triode is used in an amplifier manufactured by Continental Electronics Mfg. Co. and is similar in configuration to those being used by Brookhaven National Laboratory for the AGS injector. Once again the high average power requirements of LAMPF have created a set of design problems different from those encountered on other machines. Several components of the amplifier have failed or proven marginal from the extreme heating caused by high average power operation. The biggest problem thus far encountered concerns the upper dc blocking capacitor in the amplifier. This blocker, which was originally made with a solid machined aluminum inner conductor and a sprayed-on aluminum outer cylinder separated by an irradiated polyethylene dielectric, failed in hoop stress because of the elevated operating temperature and/or rf heating of the dielectric. The thermal expansion of the polyethylene caused the sprayed-on aluminum outer cylinder to rupture, thus destroying the capacitor. This capacitor, while satisfactory for low average power applications, is unsuitable for our application. A complete solution to this problem has not yet been found, but several variations using teflon dielectric and solid machined aluminum conductors have been tried with some measure of success. While none of the hoop stress problems have been encountered with these blockers, corona damage has been observed. The main problem with the teflon blocker would appear to be one of eliminating air voids in bonding pieces of teflon together and to aluminum. A new unit is presently under construction and hopefully will prove successful. All other problems encountered with the 7835 amplifier cavity have also been concerned with heat. The input cavity section has been found to operate at much too high a temperature and it has been necessary to circulate water through the center conductor of the input coaxial section to reduce this temperature. Another problem has been the excessive heating and resultant deformation of the rexolite output pressure barrier. A new ceramic barrier has been designed to alleviate the deformation problem and the air circulation through the amplifier has been improved to help reduce the heating. Presently the amplifier operates at 40 psi with a turbine circulating the air through an air-water heat exchanger for cooling. Even though we are presently changing the air within the cavity 10 times a minute, the inlet air temperature is running at 50°F while the outlet air is at 90°F. This 40°F difference is still too high and must be reduced. It is hoped that this can be achieved through improved circulation.

Considerable attention must also be paid to the choice of rf transmission lines. The largest commercially available coaxial lines have a 9-in. outer diameter. Again the high average power application poses a problem. If we assume rather idealized conditions, the inner conductor of the 9-in. line will reach an operating temperature of roughly 200°F when transmitting an average rf power of 200 kW at 200 MHz. For our 1 mA, 12% beam we have a 375-kW average power transmission requirement. There are several ways of coping with this problem i.e., larger line, pressurized line, or circulating water through the inner conductor of the line. We have chosen to use a 14-in. diameter coaxial line with aluminum outer conductor and copper inner conductor. With this combination the cost is approximately the same as commercially available 9-in. line, but the power handling capacity is well in excess of our requirements.

The RCA Y1068 power amplifier is rated 30 kW plate dissipation and can deliver 200-kW peak power at a 14.4% DF. This unit has been operated at this level for many hours and except for some localized heating, its operation has been very satisfactory. The water and air flow through the Y1068 has been improved and the unit should operate very satisfactorily within our constraints.

The biggest single problem in generating the rf power required for LAMPF has been the design of a reliable hard-tube series modulator for the 7835 amplifier. This problem is covered in a paper by T. G. VanVessem which also appears in these proceedings.

Conclusion

While the 200-MHz rf power systems for LAMPF are not yet fully operational, considerable progress has been made toward alleviating the many problems caused by operation at very high average powers. Many hours have been logged at the initial design level of 3-MW peak output power at 8.4% DF and work is continuing toward operation at the design maximum of 14.4% DF.

Tank #	1	2	3	4
Input Energy (MeV)	.75	5.39	41.33	72.72
Output Energy (MeV)	5.39	41.33	72.72	100.00
Energy Change (MeV)	4.64	35.94	31.39	27.28
Copper Loss (kW)	256.00	2262.00	2325.00	2331.00
Beam Power for 16.7 mA Beam (kW)	77.00	599.00	523.00	454.00
Beam Power for 8.3 mA Beam (kW)	39.00	300.00	262.00	227.00
Total Power for 16.7 mA Beam (kW)	333.00	2861.00	2848.00	2785.00
Total Power for 8.3 mA Beam (kW)	295.00	2562.00	2587.00	2558.00
Average Power for 16.7 mA Beam (kW) (8.4% RF Duty Factor)	28.00	241.00	239.00	234.00
Average Power for 8.3 mA Beam (kW) (14.4% RF Duty Factor)	42.50	369.00	373.00	368.00

Figure 1 — LAMPF Design Criteria

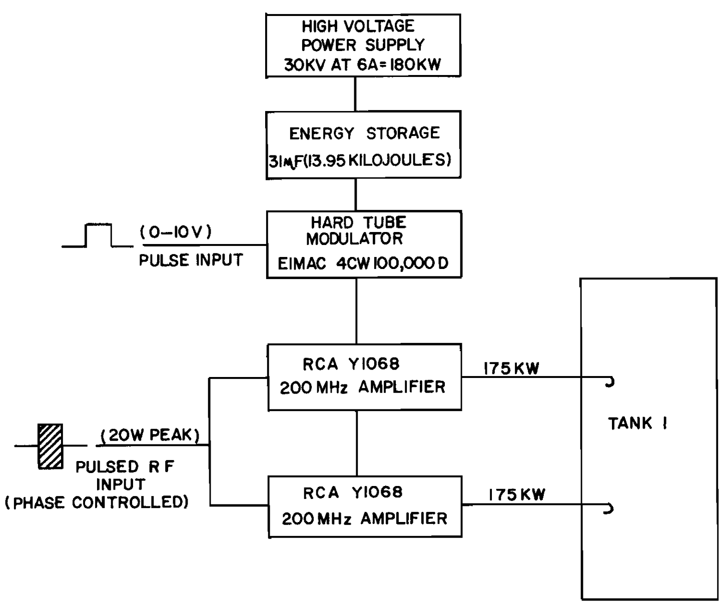

Figure 2 — RF Power System for Cavity No. 1

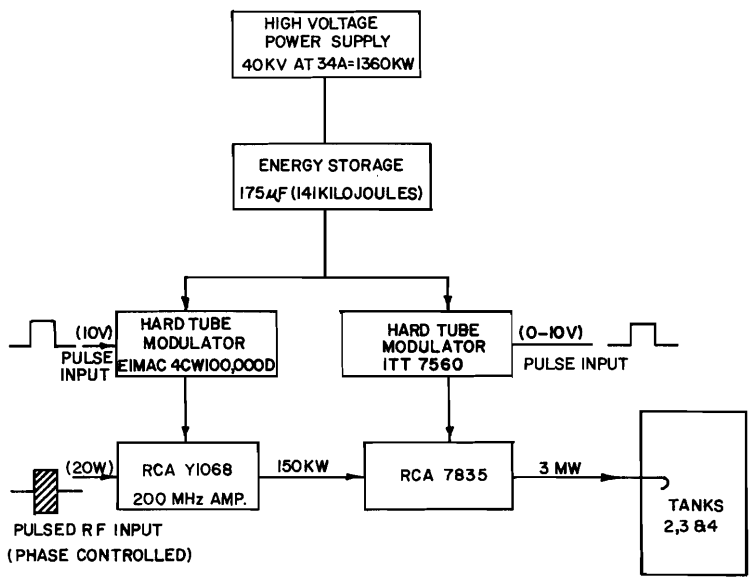

Figure 3 — RF Power System for Cavities 2, 3, and 4