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High Power rf System

Neutrino Study II

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The High Power rf System for the Neutrino Factory Cooling Channel

The ionization cooling channel requires high peak rf power sources at 201 MHz and 402 MHz to efficiently cool the muon beam, the source of the neutrinos for the factory. Bob Rimmer's rf spreadsheet list the peak rf power requirements for each section of the cooling channel. There are 162, 201 MHz cavities in the channel that require 687 MW of rf power for a pulse length of 115 μs at 15 Hz and 6, 402 MHz cavities that require 1.8 MW all at 15 Hz. A examination of the spreadsheet shows that a rf source of about 5 to 10 MW would be ideal for the 201 MHz cavities and a source of 500 to 750 kW for the 402 MHz cavities.

The rf source for the 201 MHz cavities could be supplied by current grided tubes at about the 5 MW level. However, the low gain and lifetime of grided tubes make the R@D effort to develop an alternate most attractive. Preliminary calculations at SLAC have shown that a 201 MHz klystron could be built with a reasonable amount of R&D. The gain, efficiency, and lifetime are large, greater than 50 dB, 50 % and 50,000 hours, respectively. SLAC has examined two designs a single gun diode design, and the multibeam klystron. The multibeam klystron is the most attractive in that it reduces the overall length of the tube from 7 .5 m to 3.5 to 4.0 m. The length reduction factor of the multibeam klystron and its potential for higher efficiency make it the optimum candidate for the neutrino factory. The length of the multibeam klystron is, also, consistent with the manufacturing capabilities of current tube manufacturers. Where as , the manufacture of a 7.5 m tube is a big stretch and would require new and costly facility upgrades.

Table I shows the cost estimate for a multibeam klystron system of 73, 10 MW klystrons for supplying the required rf for the cooling channel. The first item is the R&D costs to develop the 10 MW multibeam klystron. The design should be a fully integrated horizontal package incorporating the tube, solenoid, pulse transformer and high voltage terminal as pioneered at CERN for LEP. This would facilitate the replacement and installation of tubes in the facility. With a MTBF (mean time between failures) of 50,000 hours and 73 tubes , a tube, after the initial break-in period, would fail and need to be replaced every 30 days. Another advantages besides the ease of handling is the reduced cost of the rf building because of the lower building height requirement. The transmission lines from the tubes to the cavities because of the large size and costs of waveguide will be large coaxial lines of 0.3 1 to .36 m diameter pressurized to ¾ atmospheres of dry air. Power splitters would divide the rf power from each tube to supply the appropriate rf power to the cavities. Sections b1 and b2 of the cooling channel will require a 12 way splitting of the power; section b3 a 8 way ; and sections 1.1 to 2.3 a 2 way splitting of the power.

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Table I

1 0 MW , 200 MHz Klystron Cost

R&D Klystron Amortized over 73 Tubes	$ 130 k
Tube	1100 k
Solenoid	200 k
Modulator	400 k
Transmission Line components	100 k
Water Skid	60 k
Station Relay Racks, LLRF and Control	120 k
Utilities, Safety Interlocks	100 k
Installation	120 k
Total = $2330 k	
System Costs for Spreadsheet rf requirements: 73 Klystrons = $170.09 M	

For comparison the cost of currently existing tetrode based 5 to 6 MW amplifier is shown in able II. This would use the same output tube and cavity as are in use in the linacs of BNL and Fermilab. However, because these designs are dated, the first item includes R&D costs to develop a modern modulator and amplifier system. The tetrode system will require 146 amplifiers of 6 MW to supply the rf for the cooling channel. In addition even a modern day design would require two grided tube amplifier stages to drive the final 6 MW stage. Because the MTBF of grided tube is low, about 25,000, after a year or two of operation, failures in the amplifiers would occur about once or twice a week. Clearly this would not be the way to run a neutrino factory. However, the tetrode design could be used in the R&D development stages of the neutrino factory. the development phase of modernizing the tetrode amplifier would take about 6 months to a year . The development time and costs are much less than for the multibeam klystron. Rf power splitters would be used to supply the appropriate ef power to the cacities.

Table II

6 MW Tetrode Amplifier Costs

R&D Amortized over 146 Units	$ 7 k
Tubes (3 required)	240 k
Modulator	240 k
Transmission Line Components	60 k
Water Skid	40 k
Station Relay Racks, LLRF and Control	120 k
Utilities, Safety Interlocks	130 k
Installation	120 k
Total=	$957 k
System Costs for Spreadsheet rf requirements: 146 Amplifiers = $139.7 M	

The 402 MHZ system can use currently existing 750 kW rf klystron amplifiers. Because of their long length, it would be advisable to fund a small R&D development of an integrated horizontal package for the tube. Again, as for the multibeam klystron, this would improve the efficiency of tube handling and provide cost saving because of reduced building height requirement. Again, coaxial transmission lines with splitters would be used to provide the rf power to the cavities. Only 3 klystron tube amplifiers will supply the requirements of the 402 MHz rf spreadsheet. The cost of system of the three 402 MHz klystron amplifiers system is $3.525 M or $1.175 each about half of the 201 MHz multibeam klystron.

Figures 1 show a layout cross section of a portion of the rf building gallery along a 201 Mhz section. The building, Figure 2, is approximately 150 m long and 30 m wide. With the horizontal packaging of the 201 and 402 MHz klystrons the height of the building roof line need only be 5.5 m. Because of the large footprint of the equipment, the klystrons are arranged side by side and on both sides of the gallery. Not shown in the figures are the transmission line splitters required to supply the rf power to the cavities as well as the utilities. The 402 MHz klystron system foot-print will be much the same, but about half the size; and be located in sections b1 and b2 interspersed between the 201 MHz equipment.