SPECIFICATIONS COMMITTEE MEMO No. 8

Memo to: E. L. Ginzton December 17, 1958.

From: J. V. Lebacqz

Subject: PERMANENT MAGNET FOCUSING FOR "M" KLYSTRONS

Some information is available at this time on the performance of the present accelerator klystrons at constant magnetic field. Additional information will become shortly available over a wider range of voltage. The information available from Gordon Gilbert indicates that over a range of power output of approximately 2 to 1, the efficiency of the klystron will not vary by more than a few percent if the focusing currents are held constant at the optimum value at the highest peak power. In other words, one loses only about 8 percent of the peak power output if the focusing fields are not adjusted when the voltage is changed by 30 percent from its maximum value. This is shown in the table below.

Beam Voltage kv	Power Output (megawatts) With focus current optimized at each voltage	With focus current optimized at 330 kv and held constant
330	21.6	21.6
307	17.3	16.6
285	14.3	13.8
254	11.5	10.7

It is also possible to make some estimates of the power cost of the machine if one operates with focusing optimized at each power level or by keeping a constant focusing field. An actual efficiency curve averaged for 10 Mark I klystrons follows quite accurately the following curve.

$$\text{Efficiency} = .25 \times \text{power output}^{1/6}$$

If we assume that the deterioration of performance is much faster with constant focusing than actually has been measured, we can come up with a relationship for permanent magnet focusing.

$$\text{Efficiency} = .09 \times \text{power output}^{1/2}$$

Then, assuming a repetition rate of 180 pulses per second and a pulse length of 2.5 μsec cathode pulse, we find the following relationships

$$\text{Average power input} = 1.8 \times \text{power output}^{5/6}$$

for electromagnet focusing and

$$\text{Average power input} = 5 \times \text{power output}^{1/2}$$

for permanent magnet focusing. (Power output in these expressions is given in megawatts, average power input in kilowatts.) We can also assume that the focusing power is 2 1/2 kilowatts and to simplify the computations we have assumed that this stays essentially constant no matter what the operating level of the machine is. In practice the change of focusing current over the 2 to 1 power range referred above is less than about 10 percent for optimizing. We have made then two assumptions - one in which the machine is operated for 2,000 hours per year at full power (22 megawatts per klystron) and 800 hours each at levels of 20 megawatts, 17.5 megawatts, 15 megawatts, etc. This gives a total operating time of 8,400 hours per klystron. Under these conditions, the power consumption including focusing power would be 153,000 kilowatt hours per klystron with electromagnet focusing adjusted each time for maximum efficiency. With permanent magnet focusing, and with the assumed efficiency curve which is much lower than what one can expect in practice, the total power consumption per klystron per year is 150,000 kilowatt hours. Another assumption was made that klystrons would be operated for 3,600 hours at 22 megawatts, and then 600 hours at each of the following levels, 20, 17.5, 15, etc. down to 2.5 megawatts. Under these conditions, the power consumption for the electromagnet case is 170,000 kilowatt hours as against 162.5 thousand kw hours for the permanent magnet focusing system.

I believe these numbers have been taken in an extremely favorable condition for the electromagnet focusing. According to the operators of Mark III, the focusing currents are not adjusted as the tube voltage is varied. Consequently, one would expect an efficiency for the electromagnet case to be about the same as that for the permanent magnet case. If this is the case, then the additional power consumption per klystron is simply that of the focusing power supplies or 21,000 kilowatt hours from my assumptions.

I cannot at this time make any estimates of the difference in maintenance costs between permanent magnets and electromagnets. I am certain that the installation costs would be much less with permanent magnets since this eliminates a great number of interlocks, a large amount of power wiring, and a large amount of water cooling wiring. I believe that on the basis of simplicity of operation alone, the permanent magnet focusing should be given very serious consideration. It may turn out that after trying out to focus some sample 23 special tubes by permanent magnets we will have to decide in fact the magnetics are not as good as we thought they were, and it is not possible to achieve anywhere near the right efficiency with a permanent magnet-focused tube. If this is the case then the problem might have to be reconsidered but I do believe that the final decision should be made mainly on grounds of ease of maintenance and ease of operation of the machine.

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