STATUS REPORT ON THE FEASIBILITY STUDY FOR A SUPERCONDUCTING LINEAR ACCELERATOR FOR PROTONS

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Germany is considering building a proton accelerator. Looking at the accelerator situation in Europe, counting existing machines and machines that are under construction or being planned, there seems to be a gap in the region of the so called K-factory, that is to say of an accelerator that is capable of producing very copious beams of K-mesons and of course of the other elementary particles which have a rest mass in the 1 - 2 GeV region. One can obtain these from very high energy accelerators, but another way is to get them from a moderate energy accelerator with a very high current. For this purpose 5 GeV seems to be the absolute minimum and 10 GeV would be a desirable energy.

Now a conventional 5 GeV linear accelerator would either be very long, or need a high peak power and run at a low duty cycle. A low duty cycle is very undesirable from the experimental point of view, especially if one sets out to look at rare phenomena which of course will be one of the justifications for a high current machine. So we have looked at the possibility of designing a super-conducting linac which could be operated CW and which should give between 10 and 100 μA of protons. In these efforts we have been constantly encouraged by looking at what people at Stanford are doing in the same field with electrons. Our study group has been attacking the following list of problems.

1) Study of structures. You will hear more about this in the following talk. I shall only note down one figure that has been achieved so far which is, that we find effective shunt impedances of about 30 M Ω per meter for a copper structure at 760 MHz. This is a slotted iris structure with a ratio of gap length to cell length of about 0.5.

2) A group is looking at the maximum field or power that can be fed into a cavity at liquid helium temperature. This group will have results to report very soon.

3) The third group looks at various methods for producing superconducting surfaces of the highest possible conductivity. You will hear more about what they are doing later. The best figure we have been able to achieve so far is an improvement factor of 50,000 at 2400 Mc and 2° K. By improvement factor we mean the Q value of a superconducting cavity at low temperature divided by the Q value of a geometrically identical copper cavity at room temperature.

4) Then there is a group who are studying the problem of beam loading of a cavity with an analog model. Instead of injecting a (so far non-existing) proton beam into a cavity, they inject an electron beam of the same β. In this way they hope to be able to heavily load a cavity and see how it reacts. This should serve us a useful check for the theoretical calculations going on on the same subject. This group is still in the phase of building up their equipment.

5) Finally there is a number of people who are doing theoretical investigations on beam dynamics, beam loading and similar effects.

From the Stanford experience on field emission at low temperature and applying factors for the ratio peak field to the field on the axis, for the influence of drift tubes, phase angle, and for working with standing waves we feel that we should be able to get an energy gain of 5 MeV/m, so that a 5 GeV structure would be of the order of 1 km long. The power dissipation is then determined by the shunt impedance figure which was given and by the improvement factor which we can get from superconductivity.

Now the improvement factor has, for practical reasons, so far been measured at 2400 Mc/sec, whereas we want to work at about 800 Mc/sec. So some scaling is required. If we denote by the subscript Pb lead at low temperature, by Cu copper at room temperature, and add the frequency in Mc/sec as a superscript, then we have:

$$Z_{Pb}^{760} = (Z/Q)^{760} \cdot Q_{Cu}^{760} \cdot (Q_{Pb}/Q_{Cu})^{2400} \cdot (Q^{760}/Q^{2400})_{Pb} \cdot (Q^{2400}/Q^{760})_{Cu}$$

Here everything is known except the frequency dependence of Q for superconductivity. According to some theories it is f^{-2}, according to others $f^{-3/2}$, whereas some measurements at Stanford seem to indicate f^{-1} in the range we are interested in. So if we call it f^{-q}, then we obtain the following table:

Exponent q	Z_{Pb}^{760} Ω/m	Power for 5 GeV kW
1	$2.6 \cdot 10^{12}$	9.6
3/2	4.5	5.5
2	7.8	3.2

This power in the first line is small compared to the beam power of 0.5 MW, but it still is a lot if one considers that it has to be cooled away with an efficiency of about 10^{-3}. So we are not yet at the end of our struggle, but we feel that we can improve in various ways. First, we now know there are structures which have perhaps 40 or 50 Ω/m shunt impedance. But mainly we are confident from what people at Stanford are getting that the Q values also can be improved quite a lot, perhaps by a factor 2 or 3. And taking these improvements together we should then get down to an installed refrigeration power of the order of 2 or 3 kW and that would be a reasonable figure to discuss. In that case you will also notice that the installed power for refrigeration would be less than the installed power you would need for RF for a conventional linac. Our time schedule is, that we would like to have a proposal ready by the end of 1968 and we hope then, that there will be money to build such a linac or at least a first part of it. In the meantime we are also looking at the application of the same techniques to a particle separator. This should in several ways be easier because it is a smaller structure, so one would need much less refrigeration power and one does not have to stretch things to the very limit. So we think, that we can perhaps achieve the construction of a superconduction separator cavity even before the end of our study period.

DISCUSSION

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CORK, LRL: Approximately what is the cost of a kW of refrigeration?

CITRON: Dr. Smith gave me the figure of 400 kilo dollars for a 300-W unit. This is a firm offer from the firm willing to build it. For $4 million you should be able to cool 3 kW. This, of course, does not comprise everything. This is just the refrigerator. You have to throw in the cryostat, which is another $5 million, I would guess. So it looks as if the saving in power per unit length of structure is just about balanced by what you put into refrigeration. But then, of course, you can get more energy gain in the same length of structure. That is the main difference - that you push your energy gain until you get to a gradient as high as sparking, or field emission, will allow you to go.

FAIRBANK, Stanford: The cost of larger refrigerators may not go up linearly.

CITRON: I have been conservative there. The costs may not be linear, but in the worst event they would be linear, and even then it would not be an unreasonable amount of money.