CONCEPTUAL STUDIES FOR A HIGH POWER PROTON LINAC

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Abstract

A project for a proton linac delivering a 25 MW beam (average per year) is presented. It is shown how the cost of the accelerator can be minimized by a proper choice of operation : number of hours per year, CW or pulsed, etc. The project is based on the classical, copper technology. However comments are made on the possibilities offered by superconducting cavities.

1 INTRODUCTION

Feasibility studies have started in France several years ago for tritium production with a proton accelerator, the TRISPAL project. Efforts have been made in parallel in two directions.

The first one is a better understanding of the mechanisms which lead to beam losses. Halo formation have been identified by Los Alamos people [1] [2] and others as one chapter of accelerator science which deserves a special development. The question arose because no tens of megawatts beams have been contemplated yet. Here a very small percentage of lost beam produces an important out-gasing and induced radioactivity. The results of studies made for TRISPAL are presented at this conference by J.-M. Lagniel and A.-C. Piquemal [3] [4].

The second part of the studies are related to the general lay-out of the accelerator. This is what is going to be reviewed below.

2 THE DESIGN OF THE ACCELERATOR

General considerations

A large number of configurations have been proposed recently by American, Japanese and Russian laboratories for high power proton linacs, the applications being either tritium production, or the treatment of nuclear waste, or future hybrid reactors [5]. Almost all designs consist of a proton source, a RFQ section, drift-tube sections, and a high energy part, which is the longest part of the accelerator, and also the most expensive for accelerators in the energy range of one GeV. Some projects take benefit of funneling techniques. Usually the high energy part of the accelerator is operated at a harmonic frequency of the low energy part. Practically all designs are based on copper technology, even if hints are sometimes given about the possibility of using superconducting cavities. Of course each design is optimized according to the required proton production.

TRISPAL specifications

The studies started with the following specifications : a 1 GeV accelerator, delivering a 25 mA (average) beam during 6000 hours per year. Of course, what counts is the number of neutrons produced with the proton beam. So it is always possible to change the energy, the beam intensity and the number of hours of operation per year as long as the neutron production remains the same, provided that the target can accomodate the beam.

Getting a good RF efficiency

Obviously a 25 mA continuous beam would lead to a too small beam loading, that is to say a prohibitive RF power. From this point of view, a pulsed beam with a 30% duty cycle would be better since the peak current would be of the order of 80 mA, leading to a fair RF power efficiency. However most of the advantage gained on the RF power would be lost in the cost of the modulators, the additional complexity, its associated poorer reliability and the problems arisen from beam transients. It will be shown below that a 80 mA continuous beam accelerator working 3000 hours per year appears the best solution. Of course the capital cost of the RF system is higher for a 80 mA accelerator as it is for a 25 mA, but the electrical power cost is much lower if the accelerator is operated only in summertime. This is due to the fact that electrical consumption in western Europe countries is maximum during winter, and it turns out that the price of electrical power in France for large industrial consumers is almost one order of magnitude lower in August than it is in January.

Optimization

Simulations were made to determine the best accelerator for four different modes of operation, as explained in the legend of figure 1. The free parameters were the final energy and the accelerating gradient. The criterium of choice was :

the cheapest capital cost + operating cost for 20 years
a beam current not exceeding 80 mA

Since the accelerator consists for 90% of high energy structure, the optimization was made as it were purely high energy structure.

The data entered in the code were (MF stands for million of French Francs, without taxes) :

- effective shunt impedance : 35.4 MΩ/m
- phase angle : 30 degrees
- beam power P as a function of energy W for the same rate of neutron production (units : MW, MeV) [6] :
  beam power = 21.9 * (1. + 84. / (W - 400.))
- conversion coefficient from average RF power to power taken from the mains : 1.7 (CW or pulsed)
- cost of the accelerating structure : 0.755 MF/active meter, including focusing, vacuum system, tunnel, and a lengthening factor of 1.1 from cavity length to tunnel length.
- cost of the RF transmitters :
  11.7 MF/MW (CW)
  23.3 MF/MW (pulsed)
- cost of the cooling system : 1 MF/MW
- cost of the electrical distribution : 0.75 MF/MW

The result of the optimization is indicated by the circle on figure 1. The accelerator parameters are as follows :

- final energy : 700 MeV
- duty cycle :100%
- number of hours per year : 3000
- beam current : 80 mA
- cavity beam loading : 71%
- accelerating gradient : 1 MV/m
- structure length : 808 m
- total RF power : 79 MW
- beam power : 56 MW
- total power from the mains : 134 MW

the cost estimates are (in millions of French Francs, including buildings, but spare parts, taxes and contingencies not included) :

- accelerating structure : 610
- RF transmitters : 923
- total capital cost : 1830
- annual electricity bill : 50

The accelerator lay-out

The accelerator (see figure 2) consists of a 100 keV pre-injector followed by a RFQ section and DTL cavities. The RF frequency for this first part of the accelerator is 352 MHz, where a 1 MW CW klystron is available. The high energy part consists of side-coupled cavities (SCC) working at 704 MHz. Shunt impedance computations for DTL and SCC showed that 70 MeV appears as the best energy transition between the two structures. For such a 80 mA beam there is no need to use funneling techniques, so only half of the 704 MHz RF buckets are filled. The number of particles per bunch for this 80 mA beam is only 2.5 time larger as it is for LAMPF, which is considered as a safe situation from the point of view of space-charge (LAMPF delivers a 1 mA average beam with a 6% duty cycle and only one fourth of the high energy buckets filled ; this is equivalent to 32 mA if the accelerator were running

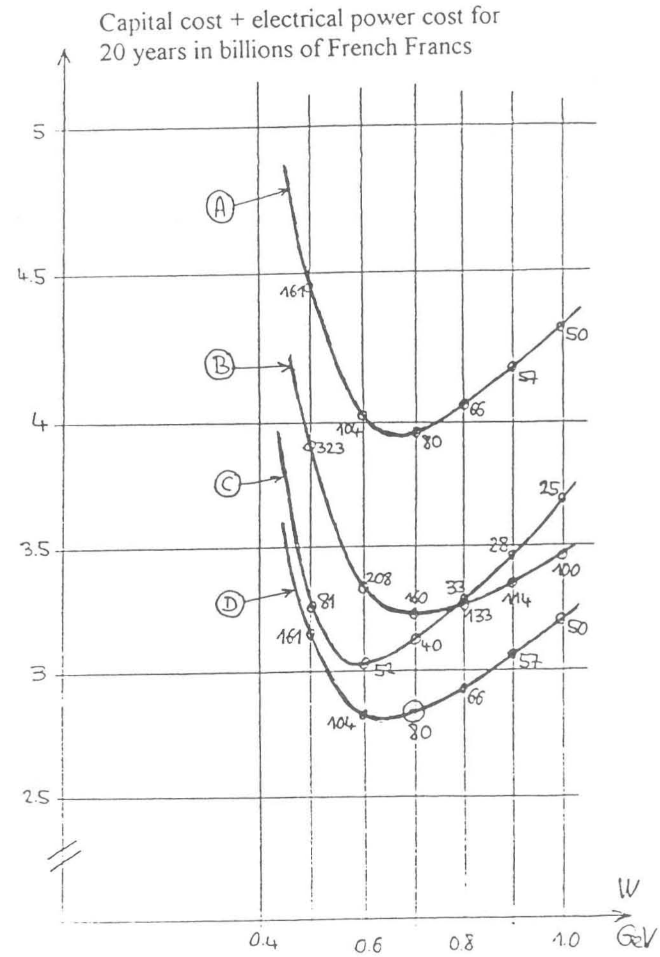

Figure 1. Cost as a function of the beam energy, for 4 different modes of operation :

A : 6000 hours per year, 50 % duty cycle.
The best gradient is 0.8 MV/m.

B : 1500 hours per year, continuous beam.
The best gradient is 1.2 MV/m.

C : 6000 hours per year, continuous beam.
The best gradient is 0.8 MV/m.

D : 3000 hours per year, contnuous beam.
The best gradient is 1.0 MV/m.

The neutron yield per year is the same for those 4 modes.

The numbers appearing along the 4 curves are the peak current of the beam, in mA.

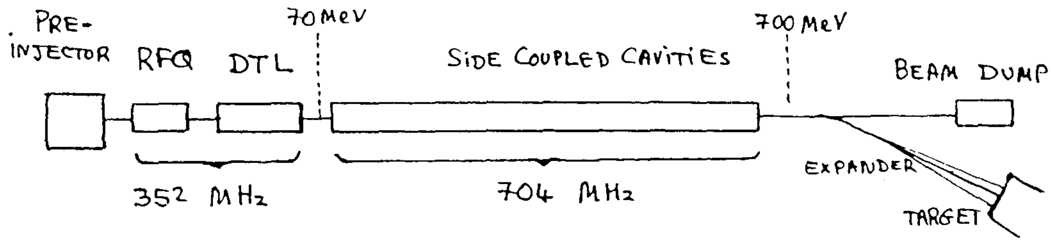

Figure 2. Lay-out of the accelerator

with a 100% duty cycle and half of the RF buckets filled). However the question of beam losses due to halo is still pending. As was said in the introduction, the problem is under investigation, but there is a good confidence that it can be solved with appropriate scrapers. The current is going to be 80 times the average LAMPF beam current, but the losses should be well below 80 times the losses experienced at LAMPF, for a number of reasons :

. more than one half of the LAMPF losses occur during the beam transient. They will not occur in a continuous beam linac.

. it is suspected that a large part of the remaining LAMPF losses are du to mismatches, which should be avoided with the advances in particle accelerator physics made since the time LAMPF has been designed.

3 SUPERCONDUCTING CAVITIES

Superconducting cavities have been used to build continuous beam linacs where copper cavities would have been limited to pulsed operation, or in storage rings to provide the high energy gain per turn impossible to achieve with copper cavities. What can be gained with superconducting cavities is the power lost in the cavity walls. But the copper cavity loading in the contemplated high beam power linacs is usually good enough (say 70%) so that saving 30% of the RF power does not change drastically the cost of the accelerator.

However superconducting cavities allow a very high accelerating gradient, let say about 10 MV/m, where copper cavities find their optimum at 1 MV/m (see above). So the accelerating structure (at least the high energy part of it) is 10 times shorter. It can be estimated that the price per meter of the a superconducting cavity is roughly twice the price of a copper cavity. Therefore it is a saving of a factor 5 on the investment cost for the cavities. There is an other advantage for the superconducting cavities : since the shunt impedance is not a critical parameter for superconducting cavities as it is for copper cavities, one can afford a bigger aperture for the beam.

But there are also severe drawbacks. A first one is the RF windows problem : in the case of the above accelerator where there is a 56 MW beam power, this power must enter the RF cavities at the rate of 0.8 MW per meter, which seems difficult to achieve with superconducting cavities. A second one is the lack of experience with superconducting linacs accelerating high power beams.

Nevertheless it one tries to imagine what would be the financial advantage of a superconducting linac, one ends up with the following figures, in millions of French Francs :

	copper	superconducting
RF system :	924	656
cavities	610	122
cryogenic plant	0	36
electrical power/year	50	36
capital cost	1830	1110
capital cost + electrical power for 20 years	2831	1822

4 REFERENCES

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