PRELIMINARY DESIGN OF A HIGH ENERGY HIGH DUTY CYCLE PROTON LINEAR ACCELERATOR

H. Leboutet, G. Guilbaud, Kervesic, Mangin, Tran
CSF - Compagnie Générale de Télégraphie Sans Fil - France

(Presented by G. Guilbaud)

One of the applications of proton linacs considered these days is the production of intense π meson beams. Roughly, this will be best achieved by use of protons of energies higher than 500 MeV. A high average current, of several hundred microamperes is desired, together with as high a duty cycle as possible.

The advantages of the linear accelerator for this application have been discussed at great length in many publications. The main one is extraction of the total beam current and the related absence of any induced radioactivity in the machine. Another is energy variation.

The Institut de Recherches Nucléaires of Strasbourg is planning to build such a meson factory and we have been attempting to evaluate the technical and financial implications of such a project. Work started about a year ago and this paper describes the present status of it.

Desired Performance

The performance we have been asked to take as an objective are the following: energy higher than 500 MeV, up to 800 MeV, average current: 200 μA, to be increased to 1 mA after some time of operation; duty cycle: 5%, this being essentially defined by the present state of the art for microwave tubes. These objectives are very similar to those of other projects and the following arguments are also the same. In short, the 200 Mc/s Alvarez structure cannot be used efficiently after some 150 or 200 MeV. One needs to look for other structures at higher frequencies, which implies a frequency jump at some point.

Our preliminary design has been guided by the following:

(a) Try and use a low voltage injector, to avoid pressurization.
(b) Limit the frequency jump to a minimum.
(c) Make the project as a whole as cheap as possible.

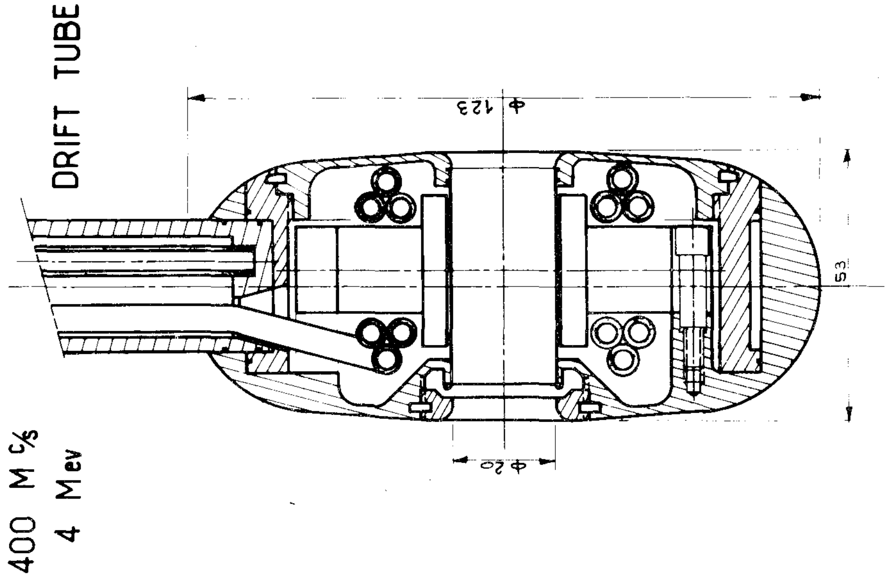


Fig. 1

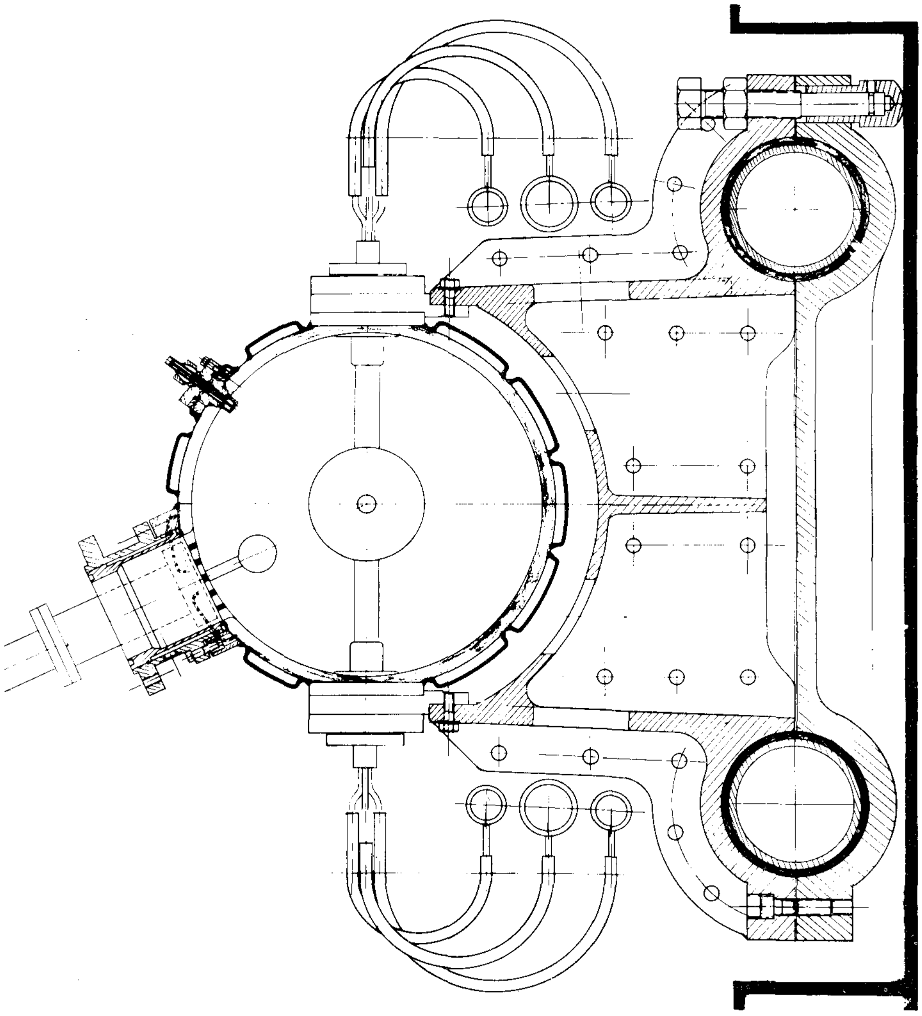


Fig. 2

Choice of the Accelerating Structures and Frequencies

A number of arguments make it desirable to operate at frequencies as high as possible at low energy: Shunt impedance is higher, the jump to the higher frequency will be smaller, and the filling time of cavities will be reduced, resulting in shorter pulses for the rf.

However, a number of practical reasons oppose this. The main one is the necessity to house, in the drift tubes, quadrupoles of a sufficient strength to compensate the rf defocusing effects.

Having looked into this with some detail, it appears that operation at 400 Mc/s at the low energy end of the machine is possible. Two possibilities have been considered.

(a) One is to inject 3 to 4 MeV protons. The general dimensions of the drift tube are then given by Fig. 1. The outer diameter is a little over 12 cm. The length is 5.3 cm. A model quadrupole is being built for magnetic testing. These figures, of course, are indicative. These lead to the general dimensions of the Alvarez structure, as shown on Fig. 2. It can be seen that the diameter of the cavity is of the order of 40 cm at most. The drift tube supports are shown here in alternate horizontal positions. This may not be final. One must position all parts so as to have enough perimeter for the water cooling which will have to be very efficient since dissipation will be of the order of 10 kW/m.

Models of 400 Mc/s Alvarez are being tested for shunt impedance requirements.

From the technological point of view, we are investigating the possibility of using an electrolytic copper tubing, supplied by a European firm who claims very good conductivity. The water pipes could be provided in the thickness of the copper, and the design of Fig. 2 could be greatly simplified.

Figure 3 shows the general structure of a tank and its support. The electrolytic tubing comes in 8 m lengths and, of course, tolerances being those of the mandril, a very precise tank can be obtained, avoiding the use of correcting bars.

(b) Another possibility is to operate on the $2\beta\lambda$ mode, at reduced rf electric field. At 500 kV/m, one is led to inject 750 kV protons into a 400 Mc/s Alvarez structure. These values correspond to the same quadrupole strength and drift tube size as before, so that Figs. 1, 2, and 3 give approximately the dimensions of a first cavity which could be used

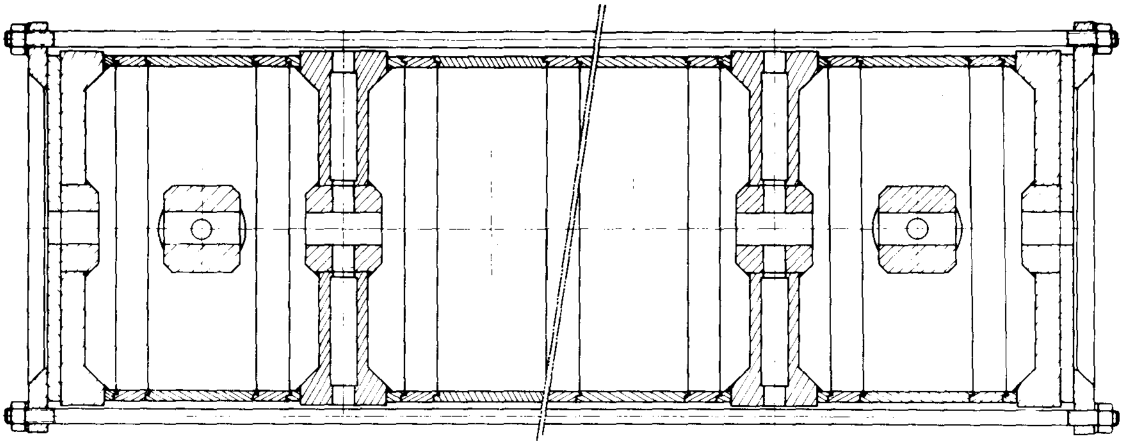


Fig. 3 400 Mc/s CROSS BAR EXPERIMENTAL MODEL

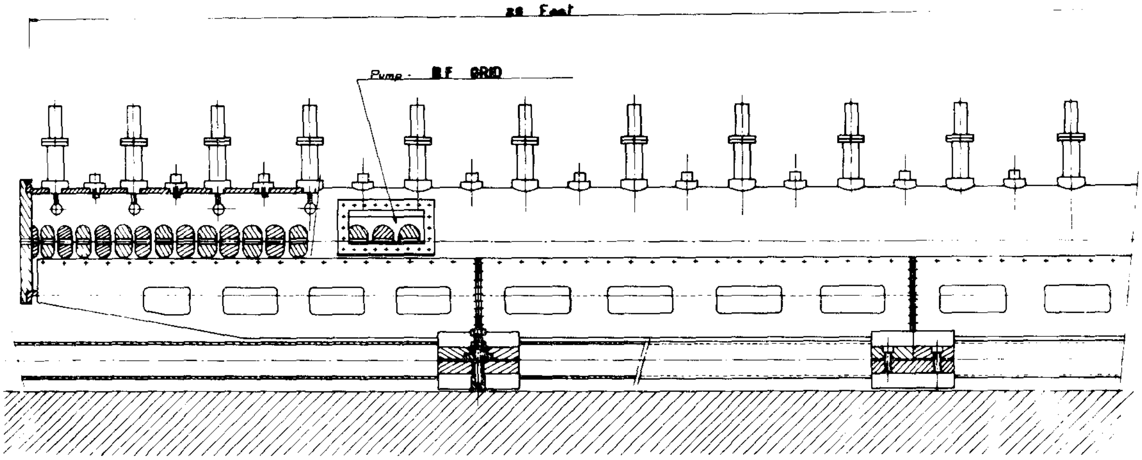
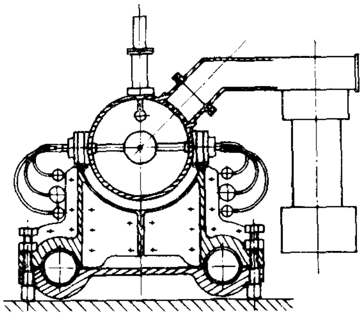


Fig. 4 400 Mc/s ALVAREZ CAVITY



to take the protons from 0.750 to 4 MeV, where they would enter an ordinary $\beta\lambda$ Alvarez structure at 1.8 to 2 MV/m.

This low injection voltage is very attractive. Of course, it involves taking some precautions. The main one is to reduce the drift tube inner hole diameter, to limit transverse field variation effects. According to $\frac{2\ \pi A}{\gamma^2 \beta\lambda} \leq 1$, the hole should not exceed 1 cm in diameter. Since the peak current will be of the order of 10 A, this should not be a difficulty.

The 400 Mc/s Alvarez structure should be used for the first 100 MeV. After this, a number of other structures might prove useful, and we are presently investigating two main types.

(a) The first is the general class of bar structures. A model is presently being built according to the drawing of Fig. 4. The model will allow making measurements on X bar structure, on the interdigital structure, by suppressing half bars, and a number of intermediate ones, by varying the angle from one cell to the next. Measurement may be underway presently and results are expected in September or October.

(b) The second class is that of iris loaded structures. Our electron linear accelerator work has been done with the $\pi/2$ disc-loaded circular waveguide. Since a passband may be desirable here, variations of this guide should be used. We are investigating the one that was previously examined for backward wave oscillations at CSF; we call it the diabolo line. The discs are cut by two very wide slots, about 120° wide, and the remaining sectors are not aligned from one cell to the next, but at an angle, which gives wide band characteristics. This circuit is about half way between the cross bar and the disc-loaded waveguide. Measurements made last fall with very low values of β are now extended to the region of β_s corresponding to 100 MeV. Such structures should be used after some 100 or 200 MeV, at an 800 or 1200 Mc/s frequency. The choice of the step energy will depend very much on the results of shunt impedance measurement. In any event, after 100 MeV, focusing can be made by magnetic doublets or triplets between short sections, of 4 to 5 m, so that the structure can be chosen without taking in account any focusing inside it.

Before turning to the general design of the machine, we should like to point out that beam-loading effects will bear heavily on the choice of the accelerating structure. We have just started an analysis of these, to understand them and determine their amplitude and ways of correcting them. It is our feeling that resonant π modes should be avoided because they lead to very large field-amplitude variations and also to very large phase shifts along the structure, causing great difficulty during the beam-loading

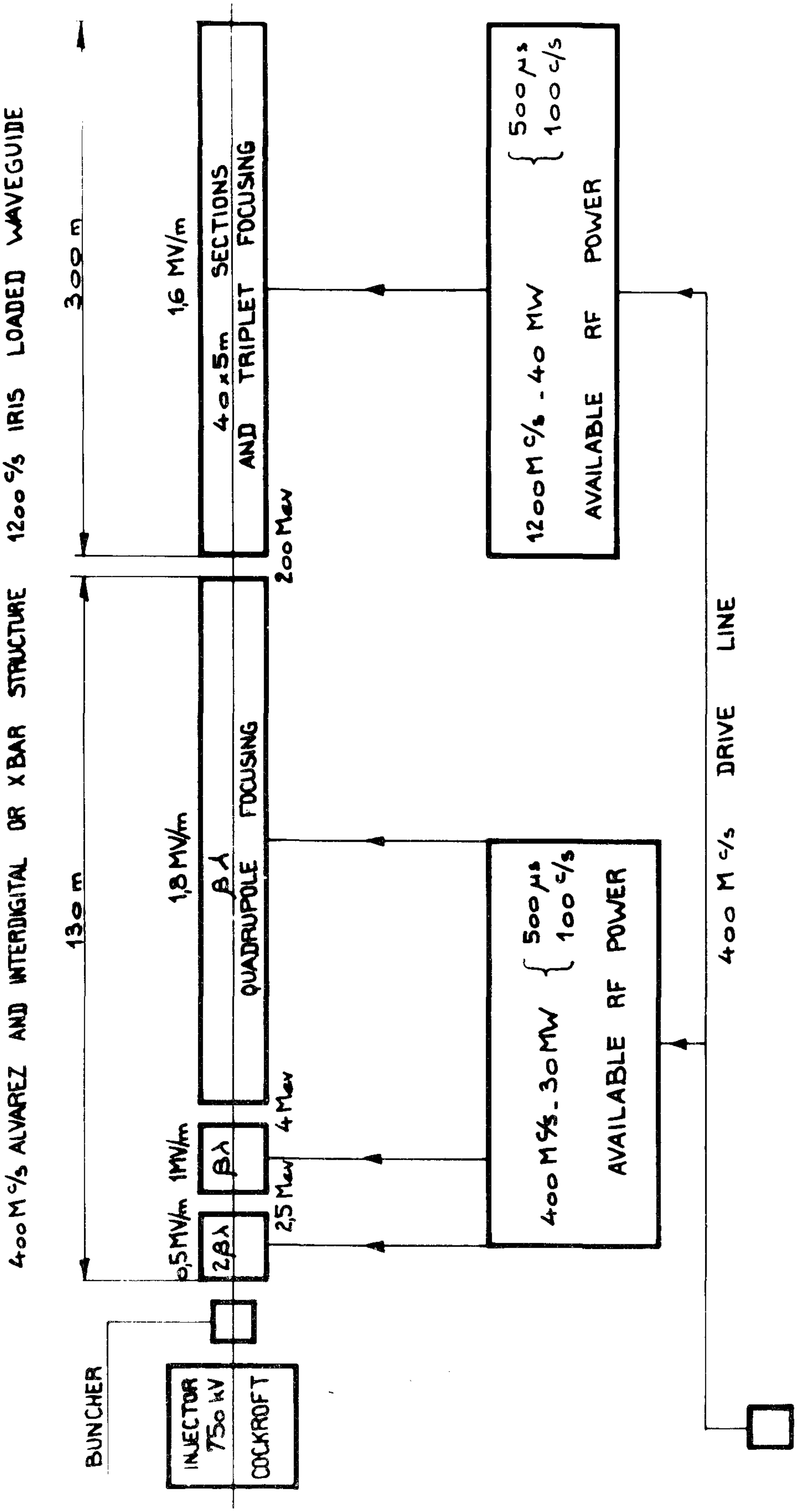

400 M c/s ALVAREZ AND INTERDIGITAL OR X BAR STRUCTURE
1200 c/s IRIS LOADED WAVEGUIDE
130 m
300 m
BUNCHER
INJECTOR 750 kV COCKROFT
0,5 MV/m
2βλ
1MV/m
βλ
2,5 MeV
4 MeV
1,8 MV/m
βλ
QUADRUPOLE FOCUSING
200 MeV
1,6 MV/m
40 x 5m SECTIONS AND TRIPLET FOCUSING
400 M c/s - 30 MW
500 μs
100 c/s
AVAILABLE RF POWER
1200 M c/s - 40 MW
500 μs
100 c/s
AVAILABLE RF POWER
400 M c/s DRIVE LINE

Fig. 5

transients. We would greatly favor the use of short travelling wave sections, where these effects will remain very small, at the cost of some complication in the use of residual power at the end of the sections. This subject will be studied in the next year; it may prove to be the most important criterion in the choice of the design.

General Design

As can be understood from above, we have not yet determined our exact choice for the circuit to be used at high energies. However, if we assume that the effective shunt impedance will average to 25 M Ω /m along the machine, one can fairly well determine its composition, including length, rf power, and later, the cost.

Figure 5 shows our present design, for the following performances:

500 MeV
4 ma peak accelerated current
5% duty cycle

Since the filling time at 400 Mc/s will be some 50 to 70 μs, 500 μs beam pulses can be used, which is very good for the higher frequency power tube.

First, we use a 750 kV Cockcroft, capable of 20 ma at 5% duty cycle. It is followed by a buncher, including beam transfer lenses. Next comes a 2 $\beta\lambda$-400 Mc/s - 0.5 MV/m cavity, either up to 4 MeV, or only to 2.5 MeV. In the latter case, a short section on the $\beta\lambda$ mode but at reduced electric field takes the protons from 2.5 to 4 MeV. After that, we have assumed that 400 Mc/s structures are used up to 200 MeV and 1200 Mc/s structures afterwards. The step energy is not determined. We have taken it to be 200 MeV here. The rf power has been estimated on the basis of an average shunt impedance of 25 M Ω /m and available evaluation of beam-loading effects. The length and rf power have been chosen by economical arguments: the product of rf losses and accelerator length is a constant, and consequently cost goes up with length for the waveguide and building and goes down with length for the rf power. The result is shown on Fig. 5. The breakdown of this over-all design in units has not been determined yet. At 400 Mc/s and up, good klystrons can be made, and some U. S. firms are already producing them. Units of 300 kW to 5 MW would lead to the lowest cost. However, these would feed about 20 m of accelerating structure each, and, according to what is known of beam-loading effects, this power would then have to broken down to feed several shorter sections. In that respect, the rf pool idea proposed by Berkeley is a very attractive solution.

Summary

As can be seen, the past year has been used to determine the main problems to be solved for the construction of such a machine and to lay the general design. The year to come will be used essentially to measure new structures and choose which one offers the best compromise at each energy, to get a good understanding of beam-loading effects, and to make as close a cost evaluation as possible, by going into detailed mechanical and electrical design.

HUBBARD: With respect to your drawing on the board, do you think there is any advantage in skewing the angles at other than 90° ?

GUILBAUD: Well, I think varying this angle will give you different pass bands and we will have to play with that.

HUBBARD: You do not have any obvious advantage in mind then?

GUILBAUD: This line was done at a time when we were working on wide-band tubes and were looking for wide pass bands and certain slopes for tuning of oscillators. Measurements made last fall do not show any great dependence of shunt impedance on this angle, but only of pass band, which may be of definite interest.