THE RF LOW LEVEL AND POWER DISTRIBUTION OF THE 100 MeV PROTON MULTITANK DRIFT TUBE LINEAR ACCELERATOR

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Abstract

The Sincrotrone Trieste proposal for a 100 MeV proton accelerator, driving a 1÷2.5 GeV booster Linac for the Energy Amplifier Project, is based on a Multi-Tank Drift Tube Linac (MTDTL) structure, since it seems to be the most simple and efficient solution for a high power, CW proton beam. The optimization of the RF system, in terms of efficiency and cost, is a crucial point in the design of the MTDTL. A possible solutions for the low level distribution and the RF power distribution are presented and analisys of the efficiencies are given.

1 INTRODUCTION

The Energy Amplifier Project, as proposed by C. Rubbia in [1,2], has been conceived for energy production as well as the incineration of the actinide waste from nuclear reactors. One of the main tasks to fullfil the stringent requirements imposed by the project is the generation of a CW proton beam with tens of MW nominal power, i.e. 30 mA @ 1GeV. No existing machine can deliver at the moment a proton beam with these characteristics and, following a suggestion by C. Rubbia, the accelerator scheme to drive the E.A. is based on a multi stage Linac [3]. The low energy injector must provide a proton current at a sufficient energy level for an efficient injection and acceleration in the main Linac. For our purposes the injection energy has been set to 100 MeV and a maximum beam current of 30 mA was assumed; this could be eventually reduced to 10÷12 mA in the near future if the energy of the main Linac could be raised to 2.5 GeV (i.e. redeployment of the existing CERN LEP superconducting RF cavities at the end of their operation expected in 2000). Since the feasibility and the reliability of the whole machine are of paramount importance, it is mandatory to keep an adequate safety margin for the machine design parameters. The scheme proposed for the pre-injector is based on the use of a commercial 3/6 MeV RFQ followed by a conventional DTL up to 100 MeV. The sequence RFQ-DTL, already successfully used in many other laboratories, is a conservative choice for a proton machine in this energy range. Nevertheless, to avoid the use of long DTL, which are difficult to tune and suffer from many difficulties coming from the necessity to house the focusing elements inside the drift tubes, as well for the high power involved, we adoped a MultiTank DTL (MTDTL) accelerating scheme, splitting the whole injector (6÷100 MeV) in a sequence of a short DTL tanks fed at a convenient power, whilst long DTL tanks would require more complicated solutions for the RF power feeding. Such a scheme would have the following advantages:

i) the focusing elements are placed outside the accelerating tanks, leaving the drift tubes free from quadrupoles, leading to a simplified heat removal from stems and drift tubes and an improvement in the temperature stability;

ii) the required RF power per tank can be kept below 200 kW, with the consequent advantage in employing standard coaxial components, already developed and available on the market, i.e couplers, feed-throughs, etc. for the RF distribution system.

The resulting disadvantages, like the slight increase in power loss and the need for a greater number of RF sources, are in our opinion acceptable. The efficiency loss of the accelerating tanks could be compensated by a higher shunt impedance due to a proper shaping of the drift tube profiles.

The length of each tank has been fixed by taking into account the previuos conditions togheter with beam dynamic requirements. The table below summarizes the main machine parameters.

Input Energy	6	MeV
Output Energy	100	MeV
Beam Current	30	mA
RF-frequency	352.21	MHz
Structure gradient	1.47÷2.44	MV/m
Average gradient	1.0÷1.8	MV/m
Number of tanks	58	
Number of gap/tank	3÷8	
Total length	87	m

Table 1. Main machine parameters.

2 RF POWER REQUIREMENTS

The suggested pre-injector design (6÷100 MeV) [4] will include 58 tanks in total with lengths ranging from 0.7 to 1.3 meters and with 3÷8 gaps per tank; Fig.1 gives a sketch of two 5-gap tanks with focusing and diagnostic elements.

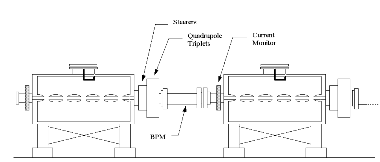

Figure 1. Two 5-gap tanks.

In Fig.2, a preliminary layout of the proposed RF distribution scheme is shown.

The whole machine will be supplied by 16 RF plants; in table 2 the power needs per plant, for 30 mA proton beam, are summarized. The reported data have been evaluated assuming an effective shunt impedance per tank ranging from 20÷25 MW; to be consevative, the values taken are roughly 10% below the corresponding ones measured of a seven gap prototype tank already assembled and tested in our laboratory. Numerical

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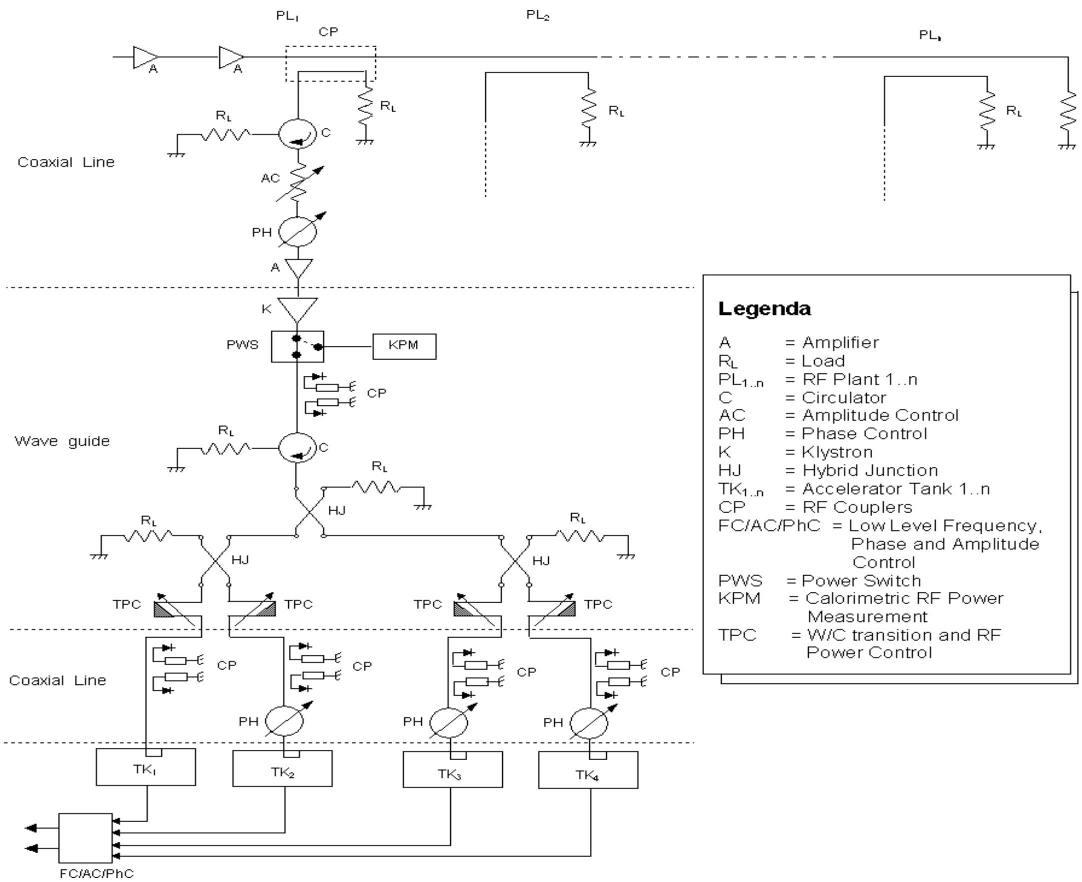

Figure 2. RF distribution layout

simulations made with Superfish on the same tank give an effective shunt impedance roughly 30% greater.

The first three plants could be fed with three CW 220÷250 KW klystrons, using a slightly modified version of the Thomson TH 2145, while for each remaining plant, a 1.1 MW tube, already in use at CERN, could be used. We have sorted the tanks to minimize the unbalanced power losses per plant since hybrid junctions are used to divide the power. For reliability reasons, the operating power level for each plant has been kept well below the maximum allowable for the tubes. We also alalysed the concept where the same 250 KW tube is used for all tanks, employing in total 55 klystrons, but a cost comparison made on the basis of informations supplied by two klystron manufacturers, EEV and TTE, was not in favour to such a solution. The main parameters of the two klystrons are listed in table 3.

Plant No.	No. of tanks for plant	No. of gap/tank	Total power (KW)	Unbalanced power (KW)
1	2	7	92	6
2	2	8	141	11
3	2	8	191	15
4	4	7/8	573	41
5	4	6/7	667	11
6	4	5/6	616	7
7	4	5	664	10
8	4	5	718	9
9	4	4	632	6
10	4	4	664	6
11	4	4	696	6
12	4	4	728	6
13	4	4	760	6
14	4	3	614	3
15	4	3	630	3
16	4	3	646	3
		Total power	9032	149

Table 2. RF power requirements for plant

	CERN Tube	TH 2145 or equiv.
Operating Frequency (MHz)	352.21	368 (to be tuned)
Typically Output Power (KW)	1100	200÷250
Efficiency (%)	65	>62
RF gain (DB)	>40	>40
Operating Voltage (KV)	100	40
Operating Current (A)	20	9.8
Total No. of Tubes to be employed	13	3

Table 3. Klystron main parameters

For the first three plants, the whole power distribution is carried out using standard 6 1/8" and a 9 3/16" coaxial lines, while for the remaining plants a WR 2300 waveguide distribution is foreseen. In this case a waveguide to coaxial transition adapter on each tank has to be provided. The RF power tuning on each tank is achieved by means of a special designed waveguide to coax transition with a remote controlled end plate short, or with a capacitive plug tuner. Further analysis will be done in the future to confirm the validity of these solutions.

On each tank we plan to control the frequency togheter with the phase and the amplitude of the resulting electic field. The frequency will be tuned and compensated by means of a proper stub, driven by a phase discriminator that compares a reference signal with the signals coming from two loops, opposite in phase and coupled with the tank. The voltage amplitude at the tank gaps could be kept constant by means of a voltage comparator while the phase control could be realized using a scheme based on a mixer which allows a rather constant sensitivity against large power variations at the input.

3 ELECTRIC EFFICIENCY

From the electric power consumption point of view, the overall efficiency of the machine has to be as large as possible. The efficiency of the whole system can be written as [5]:

$$\eta_{tot} = \eta_{ac/dc}\,\eta_k\,\eta_{tr}\,\eta_{rf/beam}$$

with:

η_{tot}	wall-plug to beam efficiency;
$\eta_{ac/dc}$	conversion AC/DC efficiency;
η_k	klystron efficiency;
η_{tr}	trasmission line efficiency;
$\eta_{rf/beam}$	accelerating cavity efficiency.

The accelerating cavity efficiency can be expressed as:

$$\eta_{rf/beam} = \left(\frac{E_0}{R_{sh} \cdot I_{beam} \cdot \cos\phi} + 1 \right)^{-1}$$

A preliminary estimation of the overall machine efficiency is summarized in the table below:

Conversion AC/DC	$\eta_{ac/dc}$	0.9
Klystron	η_k	0.6
RF Trasmission Line	η_{tr}	0.9
Accelerating Cavity	$\eta_{rf/beam}$	0.3
Wall-plug to Beam	η_{tot}	0.14

Note that η_{tr} has been evaluated averaging the efficiency on the different tanks with a mean structure gradient of 1.3 MV/m and that η_{tot} doesn't include the power requirements for the focusing elements.

4 CONCLUSIONS

A first proposal for the RF distribution system of the 6÷100 MeV CW proton Linac, based on a MTDTL, has been reported. As already said, the main reasons for adopting a modular solution, are coming from feasibility and reliability considerations, even if the cost of the RF plants could strongly affect the final choise. However, the estimated 14% efficiency seems to be consistent with the expected values reachable by means of longer DTL structures as well.

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