TANK, CELL AND BRIDGE COUPLER DESIGN FOR THE CCL OF THE ESS PROJECT

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Abstract

The design of the tanks, cells and bridge couplers of the 700 MHz 70 - 1334 MeV H^- side coupled cavity linac of the European Spallation Source project is presented. As a cost effective solution 132 2 MW klystrons will power 2 tanks each. These will be connected by bridge couplers to which the klystrons are connected. Each tank contains 16 (70 MeV) - 10 (1334 MeV) accelerating cells. The coupling coefficient between accelerating and coupling cells has been varied along the linac and has been minimised for each tank under the constraint that the field levels within each set of 2 tanks are kept constant within 1%. The bridge couplers that span gaps of $3\beta\lambda/2$ are $2\beta\lambda$ long. In order to expel the TE_{111} and TE_{112} mode in the bridge couplers from the passband in the tank, the TE_{111} is shifted away by capacitively loading the coupler with end stubs. The TE_{112} mode is expelled by using two rings where the field strengths are maximum. The bridge coupler thus obtained still operates as a single cell resonator.

1 INTRODUCTION

The European Spallation Source project ESS has been described in several papers [1]. An outline report has been written [2], and a "Final Report" is being composed. The facility with a proton beam power of 5 MW at a repetition rate of 50 Hz comprises, apart from the target stations, a 1.334 GeV H^- linac and two accumulator rings.

The proposed lay-out of the linac [1,2] has two front ends, each with an H^--ion source (70 mA, 50 kV, 10% d.c.), low energy beam transport, an RFQ, a beam chopper and a second RFQ. Funnelling is at 5 MeV. A drift tube linac (DTL) operating at 350 MHz accelerates up to 70 MeV. In the reference design a 700 MHz normal conducting side coupled cavity linac (CCL) further accelerates the H^- beam, to feed the accumulator rings. The choice of the transition energy at 70 MeV from DTL to CCL has been made for reducing activation at this transition [3],which is well below the neutron production threshold of about 120 MeV. The final beam energy of 1,334 GeV is also to minimise particle loss, here during injection in the ring due to delayed stripping of excited H^0 states [4].

For the CCL tank, cell and bridge coupler design we restrict ourselves to the reference option. General design considerations and parameters for the CCL have been given by Pabst and Bongardt [5]. Some minor changes have been implemented since, as described in the Outline Report [2]. A 2 MW klystron will feed 2 tanks connected via a bridge coupler. The tank length is determined by limiting the peak power per tank to 0.75 MW. It then varies from 1.27 m to 1.95 m, short enough to allow a constant cell length in one tank. CCL parameters are given in table 1. The intertank gaps have a length of $3\beta\lambda/2$, with β the relativistic parameter and λ the RF wavelength. This provides sufficient room for (doublet) focusing and diagnostics.

Table 1. CCL PARAMETERS

Input energy	70	MeV
Output energy	1334	MeV
Frequency	700	MHz
Repetition rate	50	Hz
Duty cycle	6.0	%
Bunch current	214	mA
Effective pulse current	64	mA
Average current	3.84	mA
Accelerating gradient E_0T	2.8	MV/m
Synchronous phase	-25	deg
Shunt impedance	29 to 41	MΩ/m
Transit time factor	0.83	
Peak power beam	81	MW
Peak power structure	113	MW
Average CCL power	12	MW
Effective peak power klystron	3	MW
Peak power per klystron	2	MW
Number of klystrons	132	
Number of tanks	264	
Tank length	1.3 to 2	m
Cell number per tank	16 to 10	
Quadrupole gradient	25 to 15	T/m
Quadrupole length	17	cm
CCL length	≤ 663	m
Bore hole diameter	4.4	cm
Trans. accept/rms emitt.	50	

2 CAVITY DESIGN

The first major goal in the design of the ESS CCL was to maximise the shunt impedance and the transit time factor of the individual cavities. Various parameters determining the shape of an individual accelerating cavity are of importance. The shunt impedance increases with decreasing bore radius, web thickness between neighbouring cells, and nose cone thickness. However, it

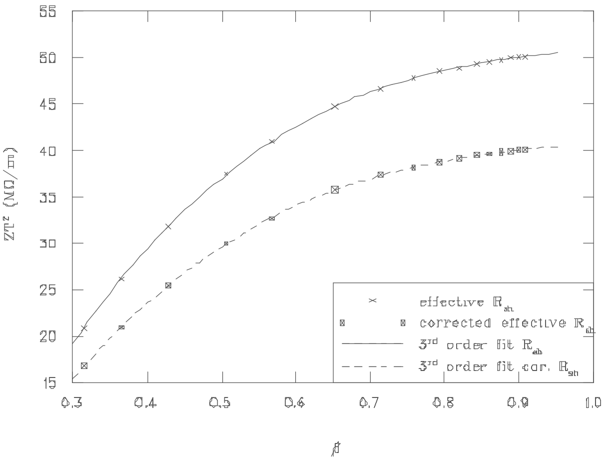

Fig 1 Shunt impedance as a function of β. The lower curve represents the values for the shunt impedance lowered by 20%.

is best to fix a number of parameters to a minimum or maximum allowable value. For example, the thickness of the web and the radii at the nose cones have been kept to the minimum value compatible with adequate cooling channels. The bore radius is fixed at 2.2 cm, approximately 7 times the rms radius of the beam. Under these constraints the shunt impedance and the transit time factor of the cavity have been optimized with the computer code SUPERFISH at different velocities (β-values), see fig. 1 and 2. The upper curve in fig. 1 represents the values calculated with SUPERFISH. It is reasonable to lower the calculated values by approximately 20% to account for the slots to the coupling cavities and for manufacturing imperfections.

In previous designs of large side coupled cavity linacs, the outer diameter of the individual cavities has been kept constant in order to minimise fabrication costs. It is believed that with modern machining techniques, such as programmable lathes, this is no longer necessary. The extra costs due to a variation of diameter will not imply a significant cost increase. The diameter may be kept constant within one tank.

With the duty cycle of 6% and the accelerating gradient of 2.8 MV/m the heat dissipated in the cavities does not exceed a comfortable 2 W/cm^2, which can be cooled with cooling channels near the nose cone, in the web and around the cavity.

With SUPERFISH, rotationally symmetric problems have been investigated on the basis of a relaxed two dimensional mesh, yielding accurate results for resonance frequencies and other parameters. The effect of the size of the coupling slots between the accelerating and coupling cavities on the resonance frequencies and the coupling coefficients have been investigated with the three dimensional computer code MAFIA.

As MAFIA performs calculations on the basis of a finite rectangular mesh this program is rather inaccurate for a precise description of the resonance frequencies. Therefore the two codes have been combined [6].

The procedure for an accelerating cavity is:

- find the dimensions of the accelerating gap and the cavity radius with SUPERFISH, for which the shunt impedance is optimal, f_{sup}.
- Recalculate the optimized cavity with MAFIA, f_{maf}.
- Calculate the coupling constant and the effect of coupling on the resonance frequency with MAFIA. This gives a frequency drop Δf for the accelerating cavity.
- Calculate the gap width for which the resonance frequency in the accelerating cavity without coupling cavities is $f_{sup} + \Delta f$ with SUPERFISH. The cavity with coupling slots should then produce a frequency of $f_{sup} + \Delta f - \Delta f = f_{acc}$.

By keeping the mesh dimensions the same for both MAFIA runs the effect due to the finite dimensions of the mesh cancel. Cold model measurements have proven that this design method is very accurate [6,7]. For the coupling cells a similar method is taken.

The MAFIA calculations show that the coupling coefficient can easily be adjusted between 2 and 8% by varying the offset of the symmetry axis of the coupling cells to the symmetry axis of the accelerating cells. The final choice for the magnitude of the coupling coefficient is largely dictated by the allowable tilt in the accelerating gradient over the tanks.

Parameters of the resulting cell shapes have been tabulated. The unloaded quality factor lies between 20000 and 30000 for the accelerating cells.

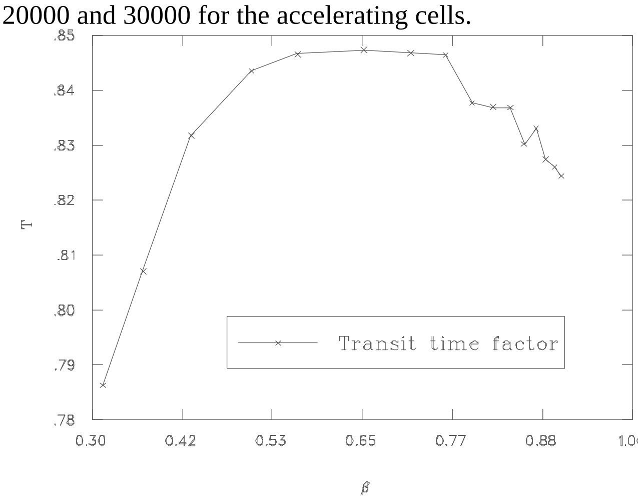

Fig 2 The transit time factor as a function of β.

3 BRIDGE COUPLER ASPECTS

An important issue is to eliminate perturbing modes from the bridge coupler in the CCL tank structures [8]. These have to be identified first. They differ from the

TM_{010} mode, and have a frequency that lies in the passband of the accelerating tanks. The passband has been determined as a function of β. It's width depends on the coupling constant k_{ac} between a coupling cell and an accelerating cell in the tank. In turn, k_{ac} depends on the allowed power loss along the tanks, on the number of cells per tank and on the quality factors Q_a and Q_c of the accelerating and coupling cells. The power loss should be at most 1%. Q_a, depending on β, has been calculated numerically with the code SUPERFISH, and Q_c is

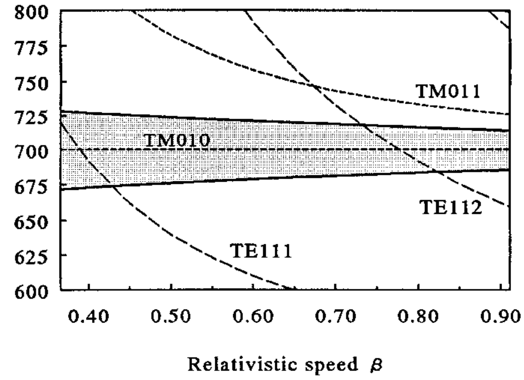

Fig 3 Passband of the accelerating tanks (gray area), and resonant frequencies in a cylindrical bridge coupler.

assumed to be 5000 or 10000. Thus a plot of the passband as a function of β can be made, fig. 3. The passband becomes narrower for higher speeds: it ranges from 672 to 714 MHz at the beginning at the accelerator (β=0.37) to 685 to 714 MHz at the end (β = 0.91).

Resonant frequencies of a cylinder cavity representing the bridge coupler have been determined both analytically and numerically, using MAFIA. The radius of the cylinder is such that the frequency of TM_{010} mode is 700 MHz. The length d is given by d = $2\lambda\beta$. There are two perturbing modes: for β = 0.38 to 0.43 the TE_{111} mode, and for β = 0.74 to 0.83 the TE_{112} mode. These have been indicated in fig.3.

The TE_{111} mode has been eliminated with a circular resonant post at the ends of the cylinder. This forces TM-modes to decrease in frequency. The TM_{010} mode has been retuned to 700 MHz again by decreasing the radius of the bridge coupler. Effectively the TE_{111} mode has increased in frequency and is not in the passband any more. The TE_{112} mode has been eliminated with two rings in the bridge coupler where the amplitude of the TE_{112} mode is at a maximum. After retuning on the radius of the bridge coupler, which now has to increase, the frequencies of the TE_{112} mode and the TE_{111} mode have increased. The TE_{112} mode is thus eliminated from the passband. The TE_{111} mode has increased in frequency, but still lies well below the passband.

Finally a five cell chain of coupled cavities consisting of two accelerating cells, two coupling cells and a bridge coupler has been considered at an energy T = 550 MeV. At this energy the bridge coupler geometry with two rings has to be used. It was shown that the resonant frequencies of the individual cavities can be tuned, as well as the coupling constant for the coupling of these cavities. Fig. 4 shows the electric field distribution in the $\pi/2$ chain mode. The $2\pi/3$ and the $5\pi/6$ chain modes are slightly mixed with the TE_{112} mode and the TM_{011} mode in the bridge coupler. To prevent this the rings of the bridge coupler have been made larger, forcing the frequencies of these modes further away from the passband. It has been shown that the elimination of perturbing modes from the passband is not sufficient to prevent modal mixing. However, this causes no problems in the accelerator.

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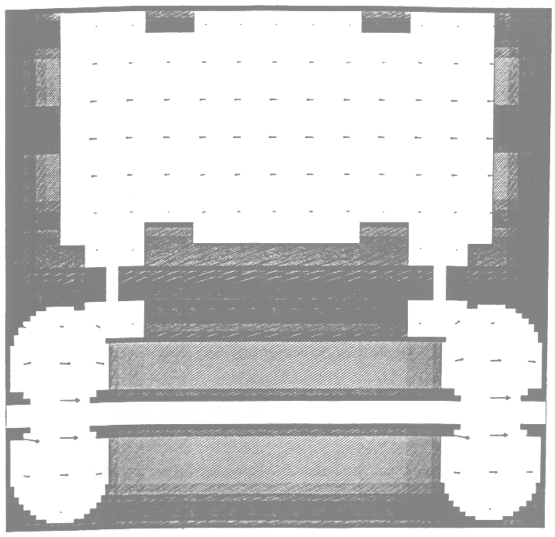

Fig 4 Electric field distribution of the $\pi/2$ chain mode.