1 MeV CAPTURE SECTION FOR LISA INJECTOR

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Abstract

1 MeV SW $\pi/2$ biperiodic CW capture section has been designed and constructed at INS Swierk in collaboration with LNF Frascati.

The main parameters of this structure and the measurements at low and high power levels will be presented together with beam dynamics simulation in measured electromagnetic fields.

Introduction

The SC linac of LISA is a constant $\beta = 1$ standing wave π-type structure[1]. Since the gun injection energy is 0.1 MeV corresponding to $\beta_o \approx 0.55$, to avoid large phase and energy dispersion in the SC linac, it was decided to add before the SC linac a normal conducting accelerating section which should increase the energy of electrons to about 1.1 MeV. The frequency of the SC linac is f_{sc} = 500 MHz; to diminish the dimensions of the added section it was decided to design an S-band structure working at the fifth harmonic of the base frequency ie. at f_{cs} = 2500 MHz. Initially it was meant to operate the system CW so we have looked for the accelerating section which can support more than 10 kW of continuous RF power losses.The choice was to take the solution similar to that of the Mainz Microtron[2] i.e. SW $\pi/2$ biperiodic accelerating section which can dissipate more than 15 kW/m of RF power.

Description of Capture Section

The capture section is a normal conducting S-band standing wave biperiodic $\pi/2$ graded β accelerating structure with on axis coupled resonators. It has been designed and constructed in Institute for Nuclear Studies at Swierk (Poland) in collaboration with LNF Laboratories in Frascati. The important problem is to calculate properly the cells lengths. Taking into account rather small phase range passed by the second chopper $\Delta\Phi = (30\text{-}60)°$ and very smooth β changes ($\beta \approx 0.55\text{-}0.94$ over the length $L \approx 1$m) we can assume that the effective electric field $E\cos\phi$ is practically constant over one cell length and changes slowly along the structure.The cells lengths are calculated for the central electron which we assume to be a "synchronous" particle i.e. a particle which travels from the center of one cell to the center of the next one during the time pT_{rf}. Here T_{rf} is the period of the RF field and p depends on the mode of the accelerating field, e.g. p = 1 for the 2π mode and p = 1/2 for the mode π or, as is our case, for the $\pi/2$ biperiodic mode. It can be shown that with the above assumptions the cells lengths are given by the formulae:

$$L_n = (\gamma_{n+1} - \gamma_n)/W_n \qquad (1)$$

$$(\gamma^2_{n+1} - 1)^{1/2} = (\gamma^2_n - 1)^{1/2} + p\lambda W_n \qquad (2)$$

where $\gamma = m/mo$ is the ratio of the mass to the rest mass, λ is the wavelength, and $W_n = d\gamma_n/dz = eE_n \cos(\phi_{cn})/(m_o c^2)$,$f_{cn}$ is the "synchronous "phase of the central electron in the bunch.

The main parameters of the structure are given in Table I and the cells lengths in table II.

Table I - Main Parameters of the Capture Section

Resonant frequency	(MHz)	f_o=2499.0
Input energy	(MeV)	W_o=0.1
Output energy	(MeV)	W_f=1.1
Pulse length	(ms)	τ = 1
Repetition frequency	(Hz)	f_r = 10
Average current	(mA)	I_a < 2.5
Total length	(cm)	L = 116.78
Number of cells		N = 23

Table II - Cell lengths in the capture section

Cell number	Length (cm)	Cell number	Length (cm)
1	3.5376	2	3.9072
3	4.1550	4	4.3678
5	4.5504	6	4.7074
7	4.8426	8	4.9594
9	5.0608	10	5.1492
11	5.2262	12	5.2938
13	5.3534	14	5.4062
15	5.4528	16	5.4946
17	5.5318	18	5.5652
19	5.5952	20	5.6222
21	5.6466	22	5.6690
23	5.6844		

Microwave Measurements

Microwave measurements were carried at Swierk throughout the whole production process[3]. They consisted of:
- testing of frequency of single resonator units;
- tuning and measurement of frequency and dispersion properties on resonators group;
- testing of impedance transformation in waveguide coupler to the structure;
- tuning and measurements of all basic parameters of the complete section before brazing;
- final tuning and measurements after brazing;
- checking of basic parameters after assembling and welding of the envelope and under vacuum.

Final tuning and measurements were done at working temperature 38 °C ± 1°.Some measurements were also made at LNF Frascati Laboratories giving practically the same results[4,5]. The values of main RF parameters as measured at working temperature are given below:

- Working frequency (at 10^{-6} Tr, 38° C) $f_{\pi/2}$=2499 MHz.
- First order coupling coefficient:

$$k = (f_o - f_\pi)/f_{\pi/2} \approx (4.1\text{-}4.4)\%$$

- Stop band Δf < 140 kHz.
- Quality factor $Q \approx$ (12500- 14500)
- Coupling to the waveguide β = (1.2-1.3)
- Cavity characteristic impedance (measured by perturbation)

$$R_c = Z_{sh}/Q = 7.6\ k\Omega$$

- Shunt impedance $Z_{sh} = R_c * Q/L \approx 80.2\ M\Omega/m$
- Effective shunt impedance (for average transit time T=0.82)

$$Z_{sh} * T^2 = 54.5\ M\Omega/m.$$

The view of the cavities of the capture section during assembling is shown in Fig. 1. Its dispersion curve, frequency spectrum of modes, and an axial field distribution E_z^2 as obtained by perturbation method are presented in Figg. 2, 3 and 4 correspondingly.

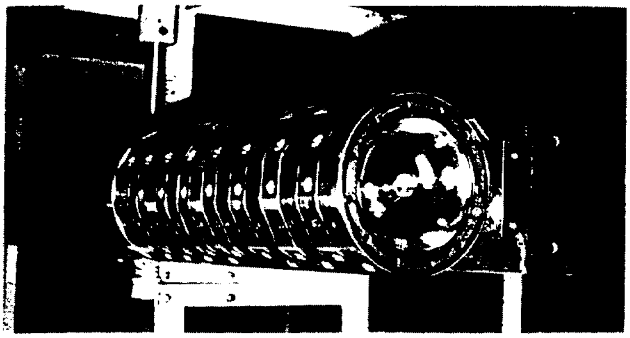

Fig. 1-View of the capture section cavities during assembling.

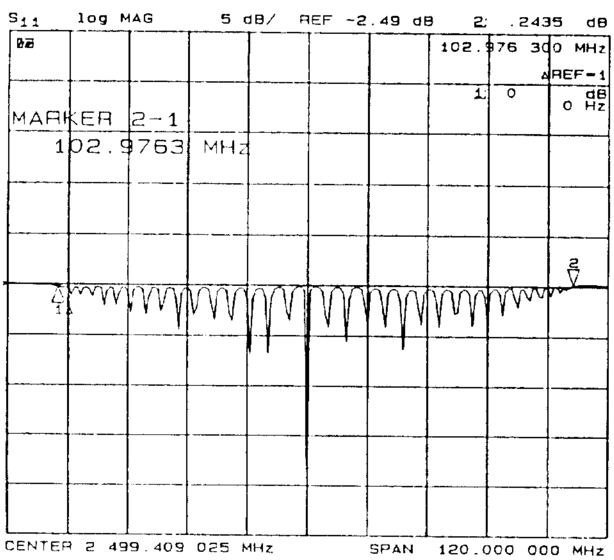

Fig. 2 - The frequency spectrum of modes in the capture section as measured by network analyzer.

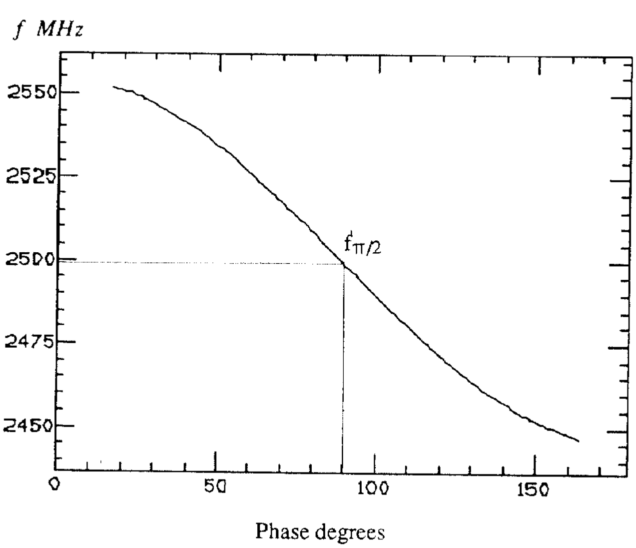

Fig. 3- Dispersion curve of the capture section.

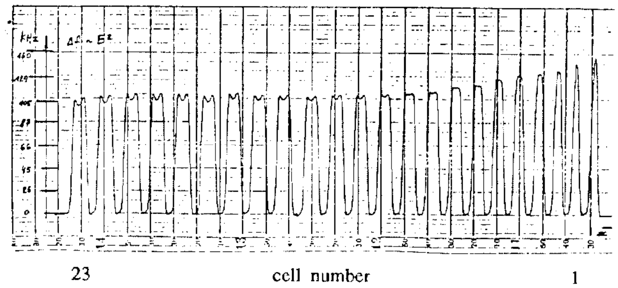

Fig. 4- Axial field distribution Ez^2 in the capture section.

The power required for the capture section consists of two parts: the power necessary to produce the accelerating field in the cavity

$$P_{ac} = \Delta V^2/(L * Z_{sh}) = 1/(54.5*1.17) \approx 15.7kW$$

and the power delivered to the beam

$$P_b = \Delta V * I_{av} \approx 2 \text{ kW}$$

The total power is then close to 20 kW.

High power measurements were made at LNF Frascati where the high power stand with the Thompson CFS klystron TH 2075 has been prepared.The aim of these measurements was to check the microwave and thermal behaviour of the section under influence of high power microwave pulses.

First run of RF power supply was accomplished without the magnetic field in the solenoid. The output power in the klystron was increased step by step taking as limiting factor instantaneous increase of pressure in the section above 2 10^{-6} Tr. After few hours steady conditions were obtained with the following parameters:

- resonant frequency	(MHz)	$f_0 = 2498.9$
- power input	(kW)	$P = 16$
- pulse length	(μs)	$\tau = 100$
- repetition frequency	(Hz)	$f_r = 50$
- water temp. in the section		$T = 37$ °C.

All above measurements were made while pumping the section with an ion pump of only 8 l/sec.

After switching on the solenoid magnetic field, even very small (about 4-5% of the nominal value), one observes on the shape of the reflected wave pulse high reflections and oscillations indicating the existence of ionization and discharges in the cavity. Also the pressure in the structure was raised up above 10^{-6}Tr. To overcome these effects a bigger ion pump of 110 l/sec was installed and the step by step conditioning was continued. Within few days almost nominal operational parameters were obtained with about 75% of the nominal magnetic field, 16 kW of the power pulse of 100 μs duration and 50 Hz repetition frequency.

As expected no anomalous thermal effects in the structure were observed taking into account that the cooling system of the structure can support much higher power losses.

The reflected power pulse shape in the case of discharges is shown in Fig. 5 and in the case of normal work is presented in Fig. 6.

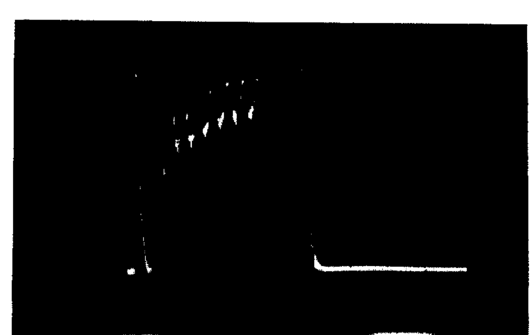

Fig. 5- Oscillations on the reflected power wave pulse from the CS cavity at the beginning of the structure conditioning with the magnetic field. Time base 10 μs/cm.

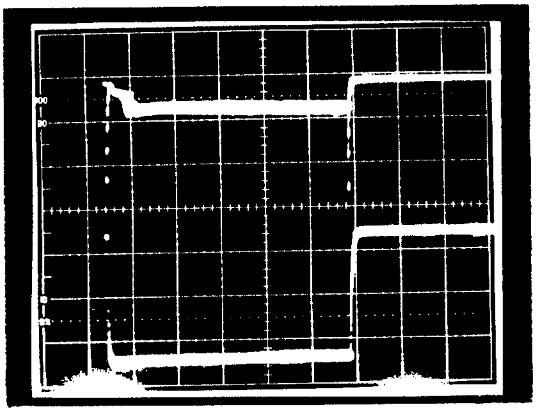

Fig. 6- Oscillograms of the input power (lower trace) and the reflected power (upper trace) in the CS section after conditioning . Input power Pi = 12kW, solenoid current I_s=40 A (=80% of nominal value). Time base 10μs/cm.

Particle Dynamics Along the Structure

The motion of particles along the section in the RF and axial magnetic field has been analysed with the aid of PARMELA. The measured solenoidal magnetic field was given in the form of curves for three current values I = 50,60 and 70 A. Since the PARMELA code at use in Frascati does not work with the tables of the field but can accept analytical expressions, a polynomial fit to the measured values of the magnetic field has been made. The result of this fit is shown in Fig. 7.

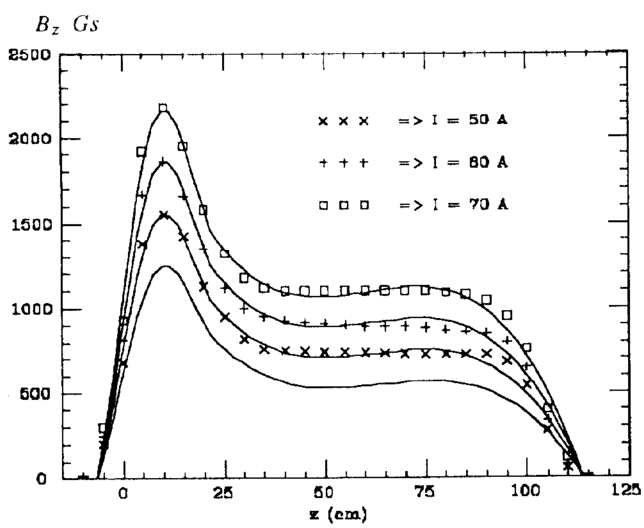

Fig. 7- The distribution of the magnetic field along the section. Continuous lines correspond to polynomial fit. The measured values are reported for comparison.

The equation of motion were then solved using the Runge Kutta method of integration.

The effect of the solenoid on the beam at the section entrance is defocalizing because of the high positive field gradient, and the defocalization begins even before the acceleration. It is then necessary that the beam should have a negative divergence when it arrives to the accelerating field to avoid an increase of the transverse envelope which could make particles hit the cavity walls; for this purpose an additional magnetic lens, not foreseen before[7], will be positioned before the capture section as near as possible to it. It will be fed by the same power supply as the main solenoid.

Particle motion simulation has been carried out for the nominal average current of 2mA, corresponding to a charge of 40pC per bunch. The beam has been followed from the gun to the end of the section. The necessary current in the solenoid is 51 A. The longitudinal magnetic field of the lens before the capture section has been simulated by a gaussian distribution with σ = 5cm; the necessary peak value is B_0 = 200 gauss.The characteristics of the bunch at the input and output of the section are given in the Table III.

Table III- Bunch parameters at the capture section ends

Parameter	Input of the capture section	Output of the capture section
σ (mm)	3.1	1.2
ε (m rad)	1.8×10^{-5}	5.6×10^{-6}
ε_n (m rad)	1.2×10^{-5}	1.8×10^{-5}
β (m)		0.24
α		0.66
E (MeV)	0.098	1.17
$\Delta E/E$ (%)	±4.5	±1.5
$\Delta p/p$ (%)	±2.4	±1.1
Bunch length (85%): (mm)	7.	2.
$\Delta\phi$ (° @ 2500 MHz)	40.	6.
I_{av} (mA)	2.	2.
I_p (A)	< 1	5.4

The longitudinal phase space is affected by the space charge force, especially at the lower energies, and so the prebuncher cannot be used at its maximum power to contain the emittance blowup produced by the current density increase in the 100 keV microbunch[7]; the bunch, when it enters the section, is 40° rf long (@2500 MHz, i.e. 7 mm). All the beam is accepted in the section and at its output 85% of the initial current is contained in ~6°, i.e. 2 mm, while the remaining 15% is distributed in long tails. The peak current is 5.4 A. In Fig. 8 the phase distribution at the exit of the capture section of 90% of the total beam is given.

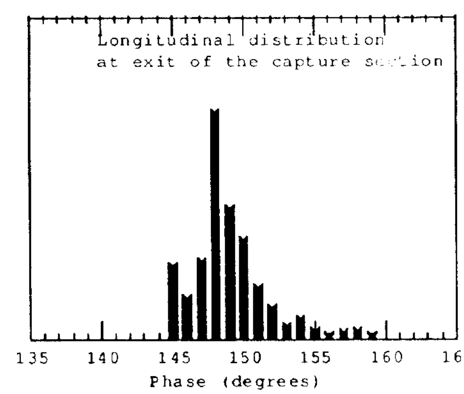

Fig. 8 - Phase distribution at the exit of the capture section.

References

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[7] C. Biscari: "Particle Dynamics in the 100 keV Injector of LISA", LNF Rep. 88/3(NT), Frascati 1988.