THE PITZ BOOSTER CAVITY--A PROTOTYPE FOR THE ILC POSITRON INJECTOR CAVITIES

V. Paramonov*, L. Kravchuk, INR, Moscow, Russia
M. Krasilnikov, F. Stephan, DESY Zeuthen, Germany
K. Floettmann, DESY, Hamburg, Germany

Abstract

A critical issue of the design of the Positron Pre-Accelerator (PPA) for the future International Linear Collider (ILC) is the operational reliability of the Normal Conducting (NC), high accelerating gradient L-band cavities. Now a Booster Cavity (BC), intended for increasing the beam energy at the Photo Injector Test Facility in Zeuthen (PITZ), and developed by a joined INR-DESY group, is under construction at DESY, Hamburg. With the PITZ requirements (accelerating gradient up to 14 MV/m, rf pulse length up to 900 mks, repetition rate up to 5 Hz) this cavity, which is based on the Cut Disk Structure (CDS), is a full scale, high rf power prototype of the cavities proposed for the PPA. The BC operation will allow us to confirm the main design ideas for the high gradient PPA cavities. A detailed technical study was performed during the BC design, resulting in some modifications for the PPA cavities, which are described in this paper. We also propose a program of rf experiments with the PITZ booster cavity for further improvements of the PPA structures.

INTRODUCTION

In the future ILC main linacs will be constructed with super-conducting accelerating cavities. But, in the indispensable ILC part - Positron Source PPA, the NC structures should be used. Proposal of the Standing Wave (SW) PPA, based on NC compensated CDS structure, has been developed [1] in frames of TESLA Project.

PPA accelerating system has two short (11 cells) capture cavities with accelerating gradient $E_0T \sim 14.5\frac{MV}{m}$ and seven longer pre-accelerating cavities (38 cells) with $E_0T \sim 8.5\frac{MV}{m}$. We select SW operating mode for PPA due to noticeably higher (as compared to Traveling Wave one) total rf efficiency and apply compensated structure basing on well known world-wide experience - such structures combine high rf efficiency with parameters stability and operational reliability.

Since that time, the booster cavity, based on the same CDS structure, has been developed [3] for the PITZ-2 facility. The BC is designed as a part of the research facility for investigations of high brightness electron beam formation, and, due to different requirements, differs in the details from PPA capture cavities. But, in principal performances - accelerating structure, maximal gradient, rf pulse length, rf pulse and average power, the cavity realize the full scale, high rf power prototype of the ILC PPA capture cavities.

* paramono@inr.ru

BOOSTER CAVITY DEVELOPMENT

The BC layout is shown in Fig. 1 and general parameters are listed in Table 1. In more details the cavity design is described in [3].

The cavity is now under construction in DESY Hamburg

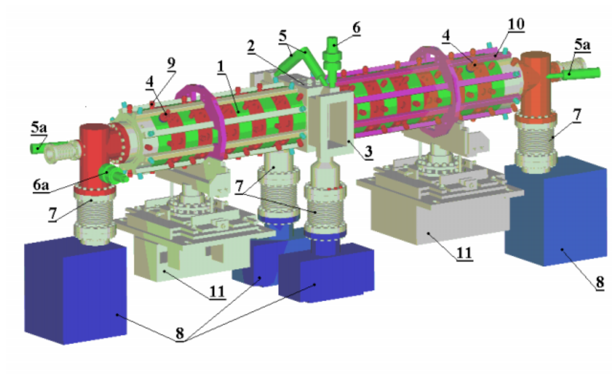

Figure 1: Booster cavity layout. 1 - regular cells, 2 - rf coupler, 3 - rf flanges, 5, 5a - photo multipliers, 6, 6a- vacuum gauges, 7 - pumping ports, 8 - ion pumps, 9 - internal cooling circuit, 10 - outer cooling circuit, 11 - support and adjustment.

with scheduled completion in the 2005 end. Now technological procedure of cells mechanical treatment is established and full scale test set is manufactured in industry (Fig. 2). Results of low level rf test measurements show very narrow cells frequencies relative spread $\approx 3 \cdot 10^{-5}$ and good parameters agreement with simulations.

Table 1: PITZ-2 BC parameters

Parameter	Unit	Value
Operating frequency	MHz	1300
Nominal gradient E_0T	MV/m	12.5
Maximal gradient E_0T	MV/m	14.0
Maximal surface field	MV/m	40.0
Maximal rf pulse power	MW	8.6
Maximal rf pulse length	μks	900
Nominal repetition rate	Hz	5
Aperture diameter	mm	30.0
Group velocity	$\%c$	5.6
Calculated Q-factor		23700
Operating temperature	C^o	≈ 45
Cooling water consumpt.	m^3/h	4.5

0-7803-8859-3/05/$20.00 ©2005 IEEE

Figure 2: Half cell of the CDS structure for booster cavity.

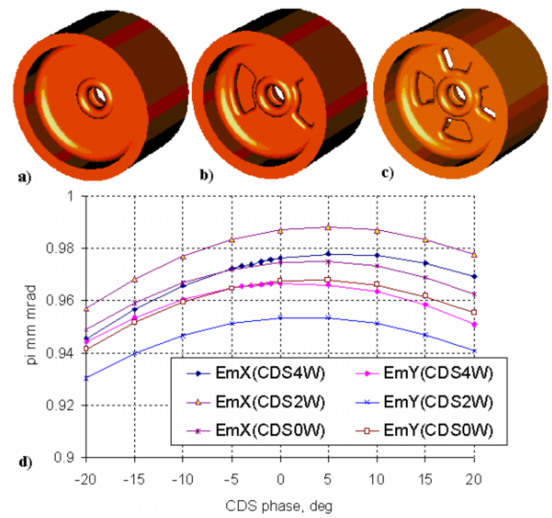

Figure 3: Top - the structure options for BD investigations, a) - axial symmetrical, b) - with two (CDS2W) and c) with four coupling windows. Bottom - d) the transverse rms beam emittance for different CDS options.

CDS DESIGN PROGRESS

During BC development the careful field quality analysis in the beam aperture has been performed to ensure minimal transverse rms beam emittance growth. The CDS options with two (CDS2W, Fig. 3b), and four (CDS4W, Fig. 3c) coupling windows were considered. The axially symmetric option, Fig. 3a, was used as a reference. Near beam axis the visible quadruple addition in the magnetic field distribution of accelerating mode was founded for CDS2W option. The beam dynamics simulations, taking into account real 3D fields maps and space charge for $1nC$ PITZ electron bunch have been performed by using ASTRA code. The plots of transverse rms emittance as the functions of the phase difference between rf gun and CDS booster are shown in Fig. 3d. For small (in transverse and longitudinal directions) relativistic ($\gamma > 10$) PITZ beams the difference in rms emittance between different CDS option is very small and beam dynamics requirements are not a point for the structure option definition.

In CDS4W option the field distortion due to coupling windows faster decreases to beam axis, leading to practically uniform field distribution in the beam region. We have no rigid requirements for field quality in PPA, nevertheless, more uniform distribution is preferable. As compared to CDS2W option, CDS4W one has another attractive features:

- higher shunt impedance Z_e value;
- higher vacuum conductivity;
- lower azimuthally modulation of the normal electric field at the drift tube surface, resulting in lower $\frac{E_{smax}}{E_0 T}$ ratio;
- lower value of maximal magnetic field at the surface;
- possibility for more flexible and effective cooling circuit.

For BC the CDS4W option has been adopted.

Symmetrical RF coupler with cooling circuit for $10MW$, $\sim 1ms$, $5Hz$ operation is developed. Such coupler cell has no dipole field component at the beam axis and one half of pulse rf power through each arm. All present $10MW$ Multi Beam Klystrons (MBK) have two output arms and for BC rf channel the scheme with two waveguide Transmission Lines (TL) (one half of total power in each line) from MBK to cavity is accepted. This case we can use well tested and relatively cheap $5MW$ power level TL hardware.

TEST AND RESEARCH PROGRAM

The main PITZ-2 research program and general facility layout are given in [4]. The BC construction and operation, except own PITZ-2 goals, will answer PPA questions.

First of all, will be confirmed design idea and parameters of the cavity, proved CDS design and construction procedure, operational features of the equivalent PPA capture cavity.

Should be constructed for long term operation at $10MW$ rf power level complete NC rf module, including $10MW$ MBK, TL rf hardware, BC, control systems, together with $1nC$ bunch beam loading, and another auxiliary systems at ILC PPA parameters. Design repetition rate for PITZ-2 $1nC$ e^- bunches - $1MHz$, (with the upgrade up to $9MHz$) will allow us investigate beam loading problem effects for ILC e^+ bunch train specifications.

At the PITZ-2 stage the facility will be equipped with two $10MW$ rf channels - one for the rf gun cavity [4] and second for the BC. These cavities will operate with high values both average and pulse heat loading, resulting in significant average frequency shift ($\delta f_{av} \approx 250kHz$ for BC) and smaller, of order several kHz, frequency shift δf_{rf-p} during $\sim 1ms$ rf pulse. Both δf_{av} and δf_{rf-p} shifts for PITZ cavities, similar to the PPA capture and pre-accelerating ones, are different. Average δf_{av} values can be compensated by own cavity frequency control systems with appropriate choice of the cavity operating temperature. Additional study is required to analyze effect of different δf_{rf-p} values and develop procedure and realize the synchronized operation of two powerful rf modules.

0-7803-8859-3/05/$20.00

CDS4W FOR PPA

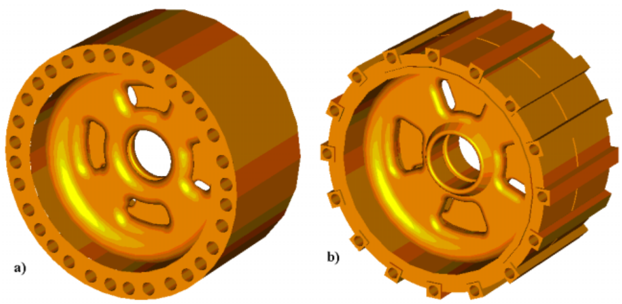

Figure 4: CDS4W options for high (a) and moderate (b) accelerating gradients in the PPA accelerating system.

Basing on the experience of BC development, we suggest CDS4W structure in two versions - for high gradient capture cavities (Fig. 4a) and moderate gradient pre-accelerating ones (Fig. 4b), for PPA accelerating system. Parameters of the PPA CDS4W versions are listed in Table 2 in comparison with previous [1] CDS2W data. For relatively short PPA cavities even reduced β_g value is sufficient for stable field distribution.

For PPA capture cavities the CDS4W option has no drift

Table 2: CDS4W parameters for PPA system. Previous [1] CDS2W parameters are shown in brackets.

Param.	**Unit**	**Value**	**Value**
f_{op}	MHz	1300	1300
E_{smax}	MV/m	≈ 40.0	≈ 40.0
E_0T	MV/m	$< 19.0 (< 15.0)$	≈ 8.5
$2r_a$	mm	47(47)	46(46)
Z_e	MO/m	36.6 (33.1)	40.4 (37.7)
β_g	$\%c$	4.4 (7.1)	5.4 (8.9)
E_0T/H_{sm}	Ohm	210 (157)	186 (161)

tubes (Fig. 4a), resulting in reduced $\frac{E_{smax}}{E_0T}$ ratio and with the same $E_{smax} = 40MV/m$ value the gradient E_0T up to $19MV/m$ is possible. Without drift tubes there is more freedom in the coupling windows formation and, according [2], one can realize higher Z_e value. Also the central region cooling is more effective.

In the first PPA part accelerating cavities are surrounded by focusing solenoid and, basing on sufficient β_g value, one can place the rf coupler cells at the cavities ends, Fig. 5. This possibility is essential for technical PPA design. Additionally, the capture cavity can be simpler entered partially in the adiabatic matching device, improving e^+ capture efficiency [1].

The average cooling capability of the CDS structure is very high. PPA pre-accelerating cavities operate with moderate heat loading is $P_{rf} \sim 8.5kW/m$, and, as BC cooling circuit study shows, only outer cooling channels, see Fig. 4b, are sufficient. It improves cavity reliability and strongly simplifies construction.

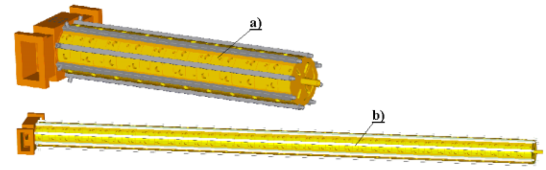

Figure 5: Capture cavity (a) and pre-accelerating one (b) for the first PPA part.

Capture cavities require internal cooling, because operate at $P_{rf} \sim 40kW/m$ and additional, depending on the source type, conventional or undulator based, particle loss, $\sim 225kW$ or $\sim 25kW$ respectively, (for total, $\sim 2m$ in length PPA capture part), [1], [5]. In both cases, the particle loss distributions, which depend on the particle shower composition (e^-, e^+, γ rays) and energy spectra, are essentially non-uniform along the cavities, resulting in different cells frequencies shifts. In such case works the original advantage of compensated structures - parameters stability against individual cells frequencies shifts. We have to control maximal temperature value in the cavity and consider just average cavity frequency shifts. With an advanced cooling circuit and moderate cooling water velocity $\sim 2.7m/s$ for CDS4W capture cavity $\delta f_{av} \approx 53kHz$ for $P_{rf} = 42kW/m$ and additional $\delta f_{av} \approx 91kHz$ for $P_p = 77kW/m$ particle loss. During $\tau \sim 1ms$ rf pulse, maximal surface temperature rise In CDS4W is $\approx 24C^o$ and heat (temperature) propagation length is$\delta l_t \approx 330\mu m$. There is no high internal stress problem, but during this time the cooling circuit practically doesn't works. Take place fast surface heating, due to P_{rf}, and volumetric heating due to P_p. Both effects lead to fast cell frequency shift during rf pulse. This problem for CDS4W high gradient option needs more study, but preliminary calculations for CDS4W show cell pulse shifts rates $\approx -1.1kHz/kW$ due to rf heating and $-1.2kHz/kW$ due to particle loss.

These values are quite optimistic for CDS4W application in the undulator based Positron Source. For CDS application in the capture part of the conventional source PPA we need more detailed study.

REFERENCES

[1] K. Flottmann, V. Paramonov (ed.) Conceptual design of a positron injector for the TESLA linear collider. TESLA report 2000-12, Hamburg, DESY, 2000.

[2] V.V. Paramonov, The Cut Disk Structure for High Energy Linacs, Pros. 1997 PAC, v.3, p. 2962. 1998.

[3] V.V. Paramonov, N.I. Brusova, A.I. Kvasha et al., Design parameters of the normal conducting booster cavity for the PITZ-2 test stand. Proc. LINAC 2004, p. 204, 2004

[4] A. Oppelt, K. Abrahamyan, J. Baer et al., The photo injector test facility at DESY Zeuthen: results of of the first phase. Proc. LINAC 2004, p. 375, 2004

[5] K. Floettmann, S. Riemann. Radiation aspects in positron sources. Workshop on Positron Sources for the ILC. Daresbury, 11-13 April 2005, http:/www.astec.ac.uk