A MULTI PURPOSE X BAND ACCELERATING STRUCTURE

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Abstract

In a collaboration between CERN, PSI and Sincrotrone Trieste (ST), a series of four multipurpose X-band accelerating structures has been designed and fabricated. The structures have 72 cells with a phase advance of $5\pi/6$ and include upstream and downstream wakefield monitors to measure the beam alignment. We give an overview of the electrical and mechanical design and describe the fabrication of the first units. We show the results of the low level RF tests. Furthermore, we present the first experiences running the structures under high power.

INTRODUCTION

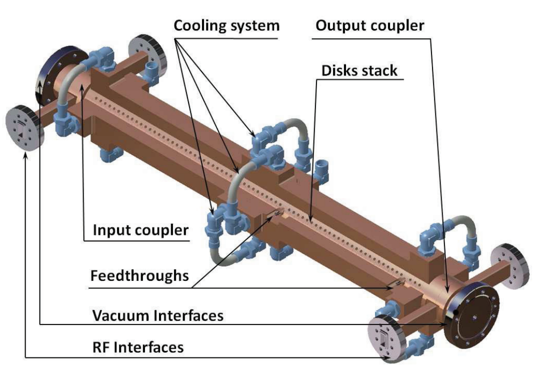

Figure 1: General view of accelerating structure.

High gradient X band accelerator technology was mainly developed for the high energy accelerator projects. Only recently has it been used in other domains like free electron lasers, where the high operating frequency is welcome to correct longitudinal phase space nonlinearities. In that context, a series of multipurpose X band structures at the European frequency of 11.99 GHz has been developed and built in collaboration between CERN, PSI and ELETTRA. At PSI and ELETTRA, it will serve for longitudinal phase space compensation at the respective FEL projects. CERN will use one of the produced structures to test break down limits and rates in the high gradient regime.

The design employs a large iris, $5\pi/6$ phase advance geometry, which minimizes transverse wake field effects while still retaining a good efficiency. Two wake field monitors provide signals from the dipole modes inside the structure, which allows to monitor the beam to structure alignment with a resolution better than 10 μm and also gives information about the internal structure straightness [1].

Fig. 1 shows a general view of the accelerating structure. Mechanically, it consists of 73 disks, of which 19 are specially designed to host the wakefield monitor [2]. CF63 flanges connect the structure to the beam pipe and four X-band WR90 RF waveguide vacuum flanges on the couplers to the RF network.

Table 1: Specifications

Beam Voltage	30 MeV
Max. Power	29 MW
Frequency (40° C)	11.991648 GHz
Iris diameter	9.1 mm (avg.)
Wake field monitors	up/downstream
Operating temp.	40° C
Fill time	100 ns
Repetition rate	100 Hz
Structure length	965 mm

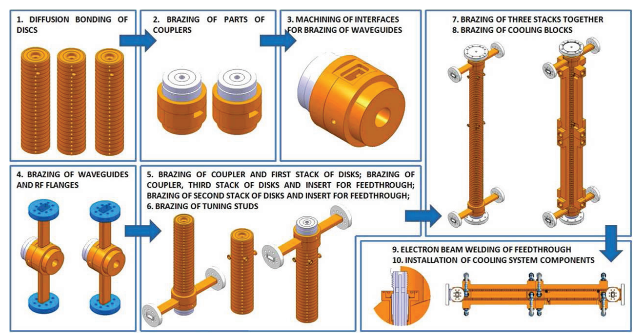

Figure 2: Fabrication steps.

The RF frequency tuning system is integrated into the accelerating structure. Based on a push-pull principle developed by SLAC [3] it allows to deform the radial wall of the cells, increasing or decreasing of the equivalent outer diameter and thus tuning the cell resonance frequency.

FABRICATION

All main parts, disks and couplers, were fabricated by VDL ETG [4] using ultra-precise turning and milling. The shape tolerance of 4 μm in the iris and cavity regions is achieved by single-point diamond turning. For diffusion bonding of the disks, the coupling faces are defined with a tolerance of 1 μm. The surface roughness is 25 nm for internal disk surfaces and 100 nm for external ones.

The fabricated cells were prepared for the assembly following the procedure [3] developed by SLAC, which includes vapor degreasing, alkaline soak cleaning, chemical etching, ultrasonic in de-ionized water and alcohol cleaning.

The structure is relatively long compared to the normal

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CLIC structures. So, to avoid possible misalignment between regular cells during bonding and also to make it fit into the normal oven used, it was split into three separate substacks for bonding. The assembly includes several assembly and heating cycle steps [5] (Fig. 2). Each stack was aligned in a dedicated V-shaped support with accuracy better than 5 μm and diffusion bonded under hydrogen at 1040°C. In parallel, the parts for the couplers and the waveguide connectors were brazed in several heating cycles. Then the couplers and special inserts for the feedthroughs were added to the stacks and in a separate step, the tuning studs required for the tuning mechanism were brazed. Finally, after brazing together all three stacks, the structure was tuned.

To solve the problem of lateral offsets between the stacks of up to 350 μm observed for the first structure, additional copper sleeves interlocking the stacks were introduced for future structures. This solution proved to be successful and resulted in outer alignments better than 18 μm.

After tuning, the cooling blocks were brazed on, after which the complete structure was baked out for 10 days at a temperature of 650° C to eliminate hydrogen traces stemming from the bonding process. As final steps, the feedthroughs for the two wake field monitors were added using electron beam welding and cooling system components such as connectors and flexible pipes were installed.

TUNING

The RF tuning system consists of four radial tuning holes per disk, each equipped with a special tuning stud brazed to the bottom of the hole. A push-pull system attached to the stud allows to either increase or decrease the equivalent outer diameter of each cell by deforming the cells wall and thus to change the cell RF frequency.

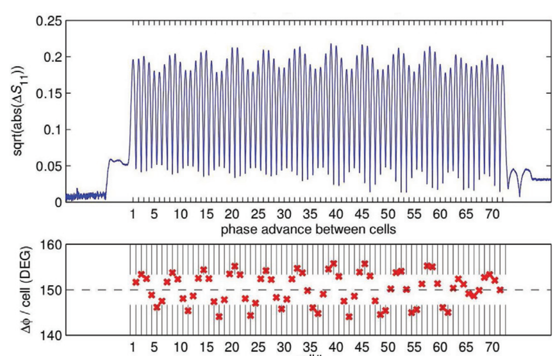

Figure 3: Field flatness and phase advance before tuning at a frequency 1 MHz below the design value.

The structure was tuned with the following procedure [6]. First, the field distribution is measured with a bead-pull. From this, the local reflection inside each cell and from this in turn the global reflection change ($|\ \Delta\Gamma_{global}\ |$ or $|\ \Delta S_{11}\ |$) is computed. With this, each cell is tuned while monitoring $|\ \Delta S_{11}\ |$ on the network analyzer.

Before presenting the results, it is instructive to discuss, what to expect as precision of untuned structure, which results from the errors in the design process itself and the precision of the fabrication.

For the design process an uncoupled model for the accelerating mode was used: all components, power couplers, matching cells, accelerating cells were designed individually, the overall behavior is assumed to be a simple superposition of all. In a later stage, a thorough numerical validation [7] was performed using SLAC's high-performance electromagnetic code suite ACE3P [9]. To obtain the resonant frequency of the accelerating mode, a reduced model using only the inner 66 cells was used, which predicted a resonance too low by 450 kHz. For a complete picture, the full structure including couplers and matching cells was simulated with S3P at the computed resonance frequency to obtain the match and the phase error of the field. The result predicted amplitude errors of 10% and phase errors of 10° for the accelerating field.

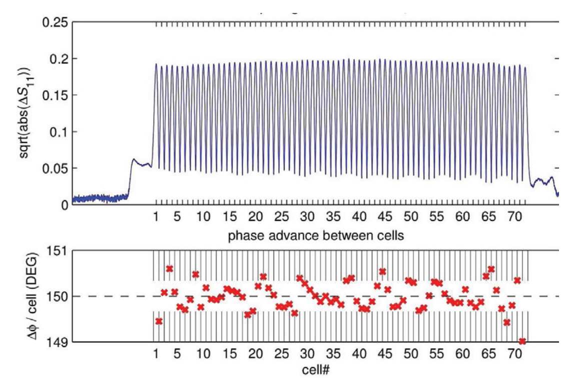

Figure 4: Field flatness and phase advance after tuning.

Based on mechanical tolerances, we should expect additional frequency errors of the order of 1 MHz. The result RF measurements before tuning for one of the real structures is shown in Figure 3. The resulting resonance frequency of the untuned structure is roughly one MHz too low, the amplitude and phase errors are of as expected from the simulations. Given these results, the tuning features also could have been eliminated, simplifying the design.

Four iterations of the tuning procedure were typically needed to finalize the structures. The field flatness and the phase advance (measured at the target frequency) after tuning are shown in Figure 4. At the operating frequency, the phase advance per cell is $\Delta\phi = 150° \pm 0.7°$. No major difficulties showed up, also for the first structure, where the inner offsets did not cause any visible field errors.

FIRST EXPERIENCE WITH BEAM

A first structure has been integrated into the linac of the FERMI FEL facility at Sincrotrone Trieste (Fig. 5) at the end of 2011[10]. It is part of the injector before the first bunch compression stage at a beam energy of 320 MeV. High power conditioning of the structure was only done to

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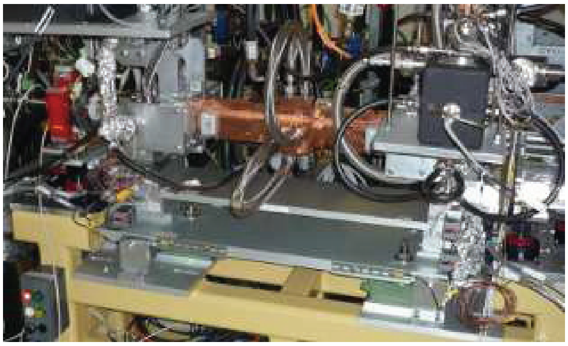

Figure 5: X band structure at the FERMI linac.

the level of roughly 30 MV/m required for operation. During conditioning, the main part of the breakdowns occurred in the waveguide network, the structure itself saw only a very limited amount.

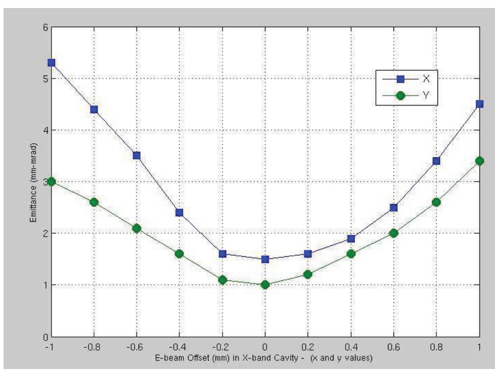

Figure 6: Beam emittance dilution versus offset.

Given the low beam energy and the small aperture, we had already in the design phase a close look at the emittance dilution of the structure [8]. Figure 6 shows the measured effect using a single bunch charge of 350 pC, offsets smaller than 100 μm can be tolerated.

Figure 7 shows, how the powered structure changes the longitudinal charge distribution of the bunches at the end of the linac. Where operation without the phase space linearization provided by the structure (as shown in the left of the figure) leads to the typical spiky charge distribution inside the bunch, applying power gives a homogeneous compression of the bunch current. A large part of the bunch is able to lase and contribute to the photon flux.

SUMMARY AND OUTLOOK

Currently, the original series of four structure has been produced, one structure is deployed at the FERMI FEL and another awaits shipping to PSI in order to be integrated into the PSI injector.

Given that the very first structure developed internal offsets, which make it unusable for the FEL projects in terms of the long range wake and the resolution of the wake field monitor, we plan to produce still another structure in order to have a common spare for the FEL projects. For the ex-

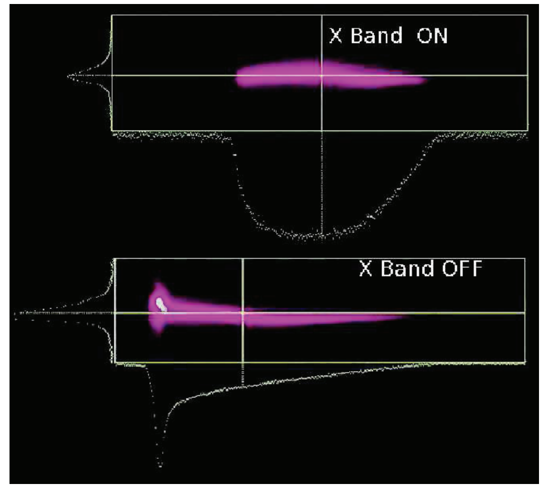

Figure 7: Single bunch charge distribution at the end of the FERMI linac, as measured with an RF deflector: horizontal coordinate corresponds to longitudinal coordinate inside the bunch.

isting structures, the next steps is to condition and put into operation one accelerating structure at the PSI injector, explore the breakdown limits at CLIC and make first tests of the performance of the integrated wake field monitors using the structure at FERMI.

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