FABRICATION TECHNOLOGIES OF THE HIGH GRADIENT ACCELERATOR STRUCTURES AT 100MV/m RANGE

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Abstract

A CERN-SLAC-KEK collaboration on high gradient X-band structure research has been established in order to demonstrate the feasibility of the CLIC baseline design for the main linac stably operating at more than 100 MV/m loaded accelerating gradient. Several prototype CLIC structures were successfully fabricated and high power tested. They operated at 105 MV/m with a breakdown rate that meets the CLIC linear collider specifications of $<5\times10^{-7}$/pulse/m. This paper summarizes the fabrication technologies including the mechanical design, precision machining, chemical cleaning, diffusion bonding as well as vacuum baking and all related assembly technologies. Also, the tolerances control, tuning and RF characterization will be discussed.

INTRODUCTION

The CLIC study has been developing two-beam technology for an e^+e^- collider with energy reach up to 3TeV collision energy in a cost effective and energy efficient way [1]. At the end of 2006, the CLIC study has changed the operating frequency and accelerating gradient of the main linac from 30 GHz and 150 MV/m to 12 GHz and 100 MV/m respectively. This major change of parameters was driven by the results from a novel main linac optimization procedure considering both beam dynamics and high power RF constraints. One of the urgent priorities is the feasibility demonstrations of the prototype X-band test structures with fully design features operating at target accelerating gradient and full pulse length with an appropriate breakdown rate. In order to speed up this process and to benefit from all the development work made by the NLC/GLC, starting from 2007, SLAC and KEK actively participated in the CLIC international collaboration. A great achievement and encouraging results have been obtained [2].

CERN's pioneer work for CLIC accelerator structures started from 1990s, two CERN made 22-cell X-Band travelling wave accelerating structures (scaled from a 30 GHz version) were successfully tested at KEK and SLAC. These structures reached 85 *MV/m* in 50 hours [3].The cells were machined on an ultra-precision lathe to a typical surface roughness of Ra200 from C101 copper supplied by Outokumpu, Finland. They were brazed in a vacuum furnace. All joints were made with silver braze.

Since the CERN-SLAC-KEK collaboration, eleven accelerator structures have been made and five of them were successfully high power tested at SLAC and KEK. Also five CERN made test structures were high power tested at SLAC. Some structures have demonstrated the stable operation with breakdown rate of few 10^{-7}/pulse/m. at accelerating gradient of 100 MV/m and pulse width of 240 ns. Therefore, it is very important to review and summarize the methods and procedures for the test structures.

FABRICATION OF TEST STRUCTURES

Test Structures and Baseline Manufacture Flow

Figure 1 shows a pair of TD18 structures. Figure 2 is a manufacture flow chart for the test structures including precision machining, cleaning, diffusion bonding of accelerator body, coupler brazing, final assembly brazing and vacuum baking.

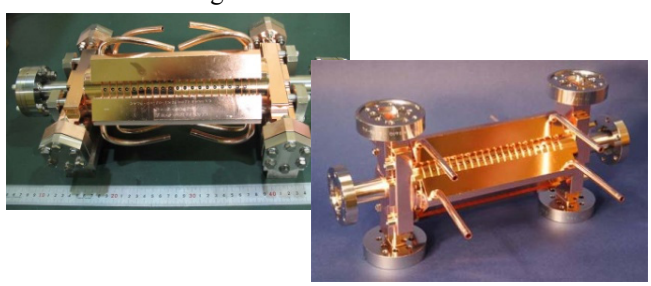

Figure 1: TD18 structures, which were high power tested at KEK (left) and SLAC (right).

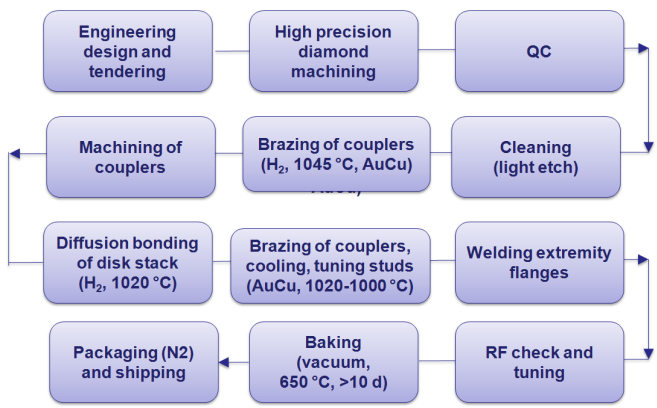

Figure 2: Manufacture flow chart.

Precision Machining of Accelerator Parts

The building blocks of the test structures are the sliced disks with thickness of one period of the periodicity. Figure 3 shows the cup side of a disk. This is a heavily damped cell with four damping waveguides. Since the recent studies are focusing on the high gradient performance of the structures, the mutual cell alignment is done with the self-fitting feature with nesting geometries.

Since most of the inside surface has non-cylindrical symmetry, most of the surface is formed by milling as seen in Figure 3 (right). The quality of this milling is important in order not to make any sharp ridges nor burrs.

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Especially important is to mill without big residual stress after machining. This care makes it easier for the following final diamond turning to form the flat surfaces to be very flat and free from burrs. Another important care is taken for the connection from the turning surface of the elliptical iris to the milled flat surface. The milled surface is positioned in its height within several micron level so that the final diamond turning will cut several microns at the iris. The tool escape motion is normal to the flat surface, and the tool mark of typically 0.4 mm radius remains. The rotation axis of the turning is referred to the outer diameter.

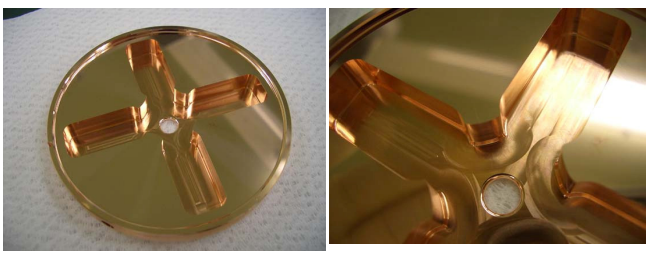

Figure 3: Typical damped cell of TD18 structure (left) and detailed shape near iris of TD18 structure (right).

Figure 4 shows typical machining flow chart of the cell. The rough machining is performed for all over the surface with undercut by 0.1 mm. Then the annealing is performed at 500°C for 2 hours, followed by a medium stage turning to make the reference surface for the milling. The milling is performed to its final design position. Finally, the finish turning is performed with using the single-crystal diamond tool.

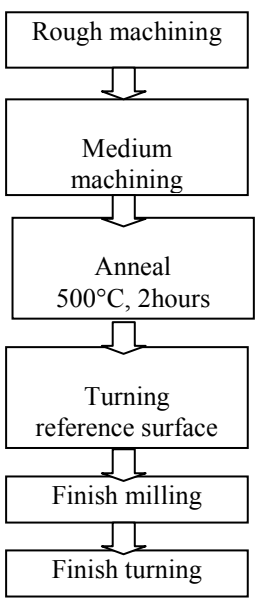

Figure 4: Machining flow chart of TD18 structure.

In these years, the final turning is usually performed by an outside company. One of the key issues of the recent disk production is the good surface flatness required for the diffusion bonding. It took some time for KEK to realize the needed flatness by the vendor by carefully designing the vacuum chucking and with as less residual stress as possible before the final turning. The flatness of every disk is assured by the vendor with the interferometer measuring patterns on both sides. The typical interferometry patterns are shown in Figure 5. Here the left figure shows only the flat surface of the cup side with masking on milled area and outer nesting area, while the right figure shows the other side of the same disk by turning the disk with respect to the vertical center line. We specified the flatness less than 0.5 μm with the criteria that adopts the same residual value when the disk is pushed between two flat plates. Actually this judgment is done by eye with seeing such two patterns as shown in Figure 5. This is needed because many of the disks can easily deform in a potato-chip pattern (as shown in the figure 5), which can easily be pushed back to flat when assembled and the disk with this type deformation can be corrected. The most difficulty from diffusion bonding point of view comes in the case that both sides of the flat surfaces become concave shape, where the disk should be re-machined or made from scratch.

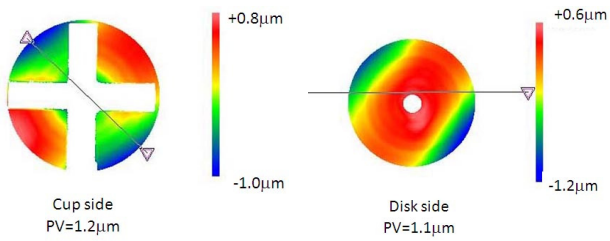

Figure 5: Typical interferometry pattern of TD18.

Chemical Cleaning

All stainless and OFE copper parts are cleaned with procedures including vapour degreasing, alkaline soak clean, 5 second etching, ultrasonic in de-ionized water as well as clean alcohol. The parts were stored in new, clean alcohol and dried with filtered nitrogen just prior to diffusion bonding. The cells should not be stored in alcohol for more than one day.

Diffusion Bonding

While bonding, great care is taken to ensure that the bonding fixtures are level on the furnace base. Alignment of the cells better than 1 mil in total is accomplished by using two alignment transits viewing the stack of cells at 90° from each other as shown in Figure 6.

Figure 6: Cell stacking for diffusion bonding.

After the entire structure has been stacked, the top of the bonding fixture is hung from the top and weights are added to achieve 0.28 MP at the bonding surface of the cells. The TD18 cells bonding surface was approximately 24.2 cm^2, so the weight used was about 68 kg and the T18 structure bonding surface was approximately 9.7 cm^2, so its weight used was about 27 kg. The stacks were diffusion bonded at 1020°C for one hour, using standard operating procedures in an externally heated, hydrogen atmosphere furnace with 4.5 m^3/hour of hydrogen flow.

Brazing and Assembly

After the stack is bonded and leak checked, it is brazed to other parts and sub-assemblies (couplers, cooling blocks, tuning pins, drift tubes…) using lower melting point alloys at each step. Typical alloys are 25Au/75Cu, 35Au/65Cu, and 50Au/50Cu and may be wire (.030" Dia.), powder or sheet (.002" thick), depending on the braze being performed. The assembly is leak checked after each braze. After the final braze, the flanges are welded on to the drift tubes and the structure is ready for RF Tuning and Characterization.

RF Tuning and Characterization

In order to keep the structure cleanness, the microwave tuning was completed using non-resonant perturbation technology with bead pulling measurements.

Vacuum Baking

Figure 7: Two structures and their vacuum container.

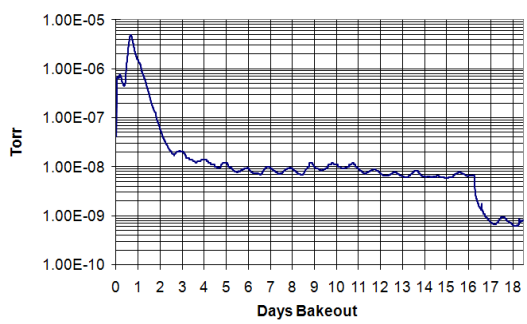

Figure 8: Vacuum profile: 1×10^{-8} Torr for most of baking time and 1×10^{-9} Torr after cooling down.

The structures are installed in a super clean stainless container with separate high vacuum and baked in a vacuum furnace at 650°C for at least 10 days. Figure 7 and 8 show the vacuum baking set-up and vacuum profile respectively.

ALTERNATIVE DESIGNS

One of the alternative CLIC accelerator designs is the choice of the quadrant as a constituent of the accelerating structures. A structure can thus be formed from four quadrants in which the cells, irises, slots, damping waveguides and other subsystems are milled into each piece as shown in Figure 9 [4]. One of the advantages of this novel accelerating structure design and assembly compared to traditional structure is the reduction of the number of pieces per structure to four and a significantly decrease in surface area to be machined. During the engineering design sharp edges between the RF surfaces of the quadrants have to be replaced by chamfering with a radius of about 50 µm. This is important for the quadrant misalignment in order to avoid zones with high electrical field concentration. The achieved surface roughness from the milling technology is Ra100 only, compared to Ra25 obtained by single-point diamond turning.

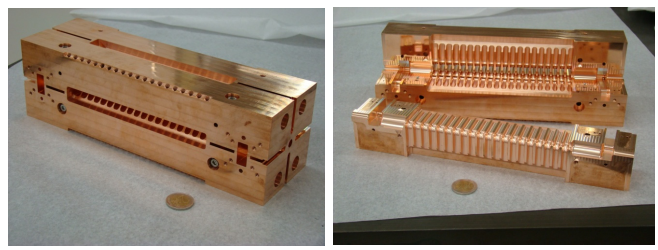

Figure 9: Quadrant structures.

OUTLOOK

Strong collaboration and coordination are essential to realize our ultimate goal. The fabrication of some improved CLIC nominal design structures (two T24 without damping slots and two TD24 structures with damping slots) is under way and they will be high power tested in the summer 2010 at KEK and SLAC. Next, the design and fabrication of accelerating structures equipped with damping features and wake-field monitors as well as the successful tests of up to ten CLIC prototype structures to meet all specifications will be completed in the next couple of years.

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