# HIGH PRECISION MANUFACTURING FOR LINACS*

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*Abstract*

A big effort in R&D focused to the LINAC devices together with the know-how already deployed through emblematic projects, places DMP in the state of the art of the extreme precision mechanics. This mechanic culture makes DMP a natural partner in early stages of design or driver of a comprehensive solution, optimizing industrial risks, quality and due date. Surface roughness below 1 nanometer, figure errors better than 50 nanometers in OFE copper enhances lifetime and performance of many devices for LINACs. Research in joining techniques and combining several alternative technologies to traditional machining, improves figure stability and makes complex cooling systems possible.

## INTRODUCTION

DMP is well known as provider for high precision machining. Established as a reliable partner in high technology, HTS (High Technology Solutions) completes the cycle from engineering to design. Different kinds of products have been developed together for LINACs.

Some of the technical goals achieved in the ultra high precision manufacturing field for accelerating structures are highlighted in this paper.

## ULTRA HIGH PRECISION

### *Overview*

The field of ultra high precision requires considerable experience, not only in frequently used materials like aluminium or steel but also in titanium, invar, OFE copper, armco, nimonic, alumina, etc. Ultra high precision can only be achieved in a fully controlled process where room temperature must be rigorously controlled with accuracy within ±0.1 K in order to avoid any distortion due to thermal dilatation. Computer numeric control (CNC) machines for lathing, milling, grinding and electric discharge machining (EDM) must enable dynamic control as a function of the temperature of the piece being machined and the temperature of the spindle. All manufactured pieces must be 3D scanned in house to enable a closed loop between different steps. High precision and ultra low probing force (0.001 N) 3D coordinate measuring machine (CMM) with accuracy below 0.3 µm are used to validate devices in a clean environment. Higher forces will damage the pieces above the specifications; the next picture shows the impact of a low force head, with a 0.8 mm Ø stylus over a OFE Cu flat surface.

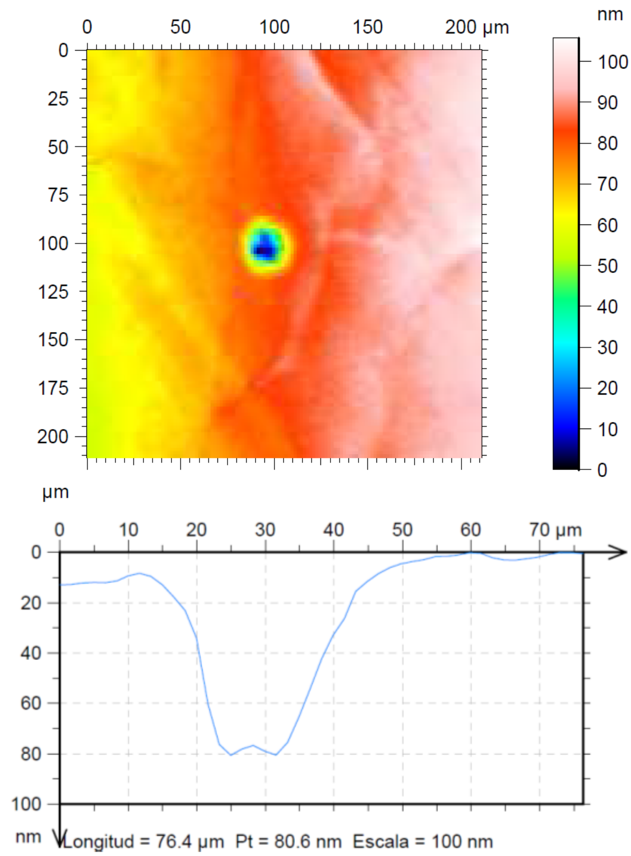


Figure 1: Impact on flat OFE copper of a 3D CMM 0.8 mm Ø stylus. The result is a crater 80.06 nm in deep.

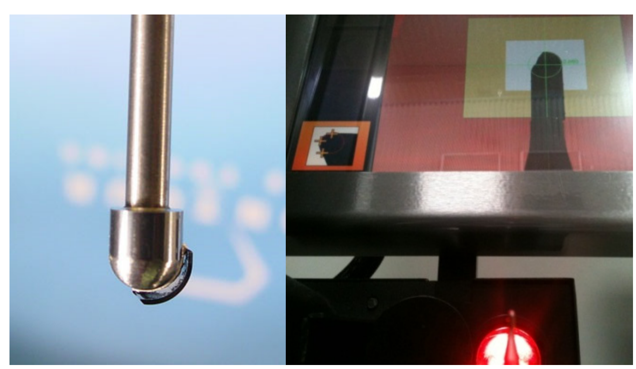

Figure 2: Image of a diamond tool and a laser waviness measuring system.

Other kind of devices combining interferometry and confocal techniques are also necessary for high precision non-contact measurements (resolution below 0.1 nm).

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Special milling tools made in single crystal diamond are used for the final steps mounted in up to 180.000 rpm spindles (see Figure 2).

The vacuum temperature profile for stress relieving must be completely controlled; otherwise physical properties like grain growth, oxidation and hardness can become undesired.

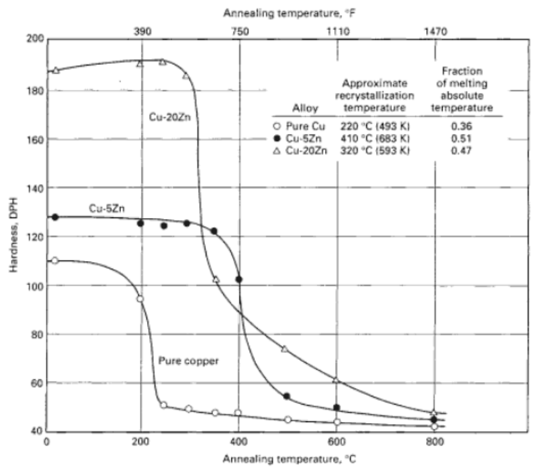


Figure 3: Hardness as a function of the annealing temperature (ASM International).

HTS contributes during engineering and the process definition phases. The aim of specialization is the manufacturing of state-of-the-art devices.

## MANUFACTURING OF ACCELERATING STRUCTURES FOR CLIC

CLIC (Compact Linear Collider) would provide significant fundamental physics information even beyond that available from the LHC as a result of its unique combination of high energy and experimental precision. CLIC aims at a center-of-mass energy range for electron-positron collisions of 0.5 to 5 TeV.

The accelerating structures are made of discs which Figure error is 4 µm, flatness 1 µm, parallelism 2 µm and surface roughness 0.025 µm (Ra) [1]. This means that ultra high precision procedures must be developed and large investment must be performed in R&D, ultra high precision machines and human resources.

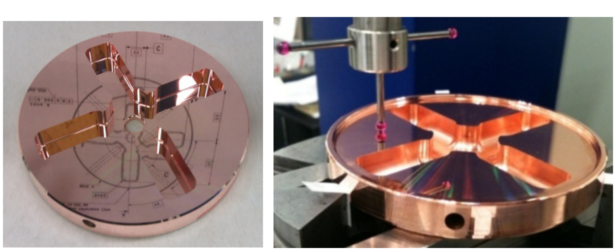

Figure 4: Manufactured discs for CLIC.

Since all discs will be used in ultra high vacuum ($10^{-10}$ mbar), grinding is not allowed, and only silicone and halogen free cutting fluids are permitted. Moreover, strict handling procedures have been implemented, among other taken cares.

Special tooling was developed to avoid micro-vibration and stress during the machining and the scanning phases.

## MANUFACTURING OF PETS AND POWER EXTRACTION COUPLERS

The CLIC power extraction and transfer structure (PETS) is a passive microwave device in which drive beam bunches interact with the impedance of the periodically loaded structure, generating RF power for the main Linac accelerating structure (this means negative acceleration) [1].

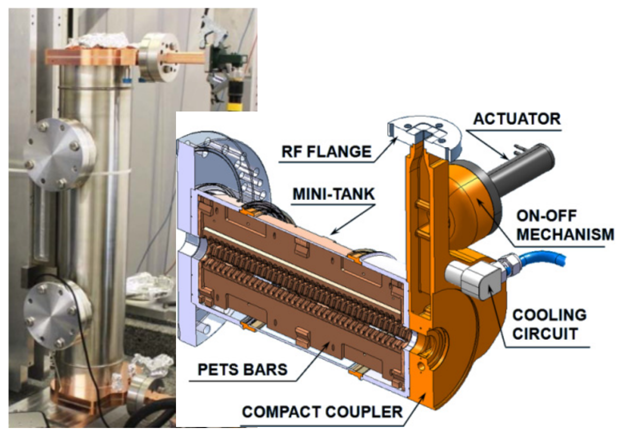


Figure 5: PETS tank with compact extraction couplers; sketch and picture (courtesy CERN and CIEMAT) [1, 2].

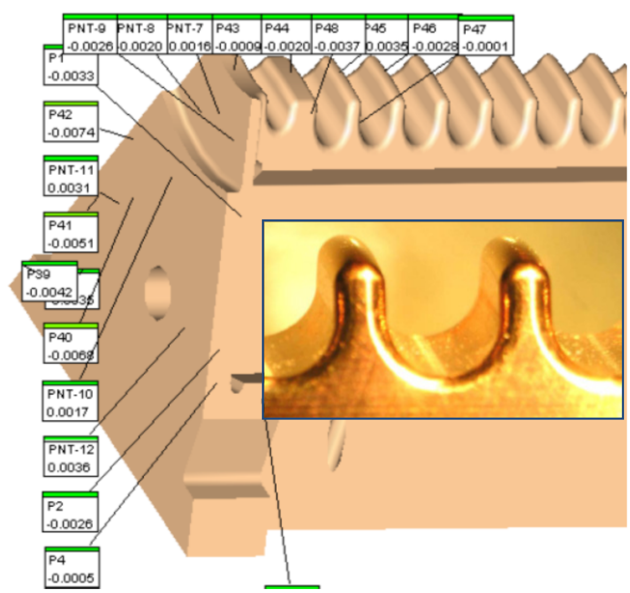


Figure 6: High precision is needed in this kind of structures (deviations in mm with 4 decimal places).

PETS are composed of 8 bars in OFE copper milled with 15 µm shape accuracy in 520 mm length (the manufactured version). Each octant, compact couplers, cooling circuits and special flanges has been completely manufactured [3-5].

Engineering design was carried out at CERN and CIEMAT, and manufacturing was performed by DMP [2].

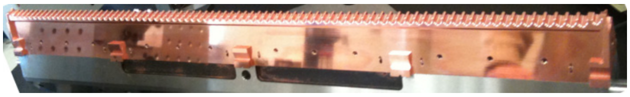

Figure 7: Double length (520mm) CLIC PETS octant.

The surface roughness was better than 0.3 μm.

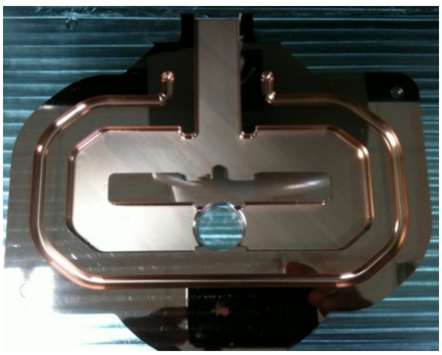

Figure 8: Halve of a power extraction coupler.

## DRIFT TUBES FOR LINAC4

The goal of the Linac4 project is to build a 160 MeV $H^-$ linear accelerator replacing Linac2 as injector to the PS Booster (PSB). The new linac is expected to increase the beam brightness out of the PSB by a factor of 2, making possible an upgrade of the LHC injectors for higher intensity and an increase of the LHC luminosity.

The drift tube linac (DTL), is an accelerating structure which increases the beam's energy from 3 MeV to 50 MeV. The DTL is made of copper-plated stainless-steel vacuum tanks containing a series of precisely machined and aligned copper electrodes or drift tubes (see Figure 9). The electric field developed between the drift tubes by means of powerful radio-frequency (RF) generators provides the acceleration to the particle beam. The heat deposited by the RF currents in the drift tubes and tank walls is removed by a water-cooling system.

Each of the 108 drift tubes and their individual mounting pieces consist of 9 parts of different sizes (Figures 9 and 10). While most components are series items of one or two types, four copper parts have parameterized dimensions varying for each drift tube, and they require special 3D machining.

Outer surface finished roughness of three copper parts of Ra ≤ 0.5 μm was achieved by milling and < 0.3 μm, by lathing. This is critical to limit ohmic RF losses.

Tolerances down to ±0.01 mm are requested on most parts for precise assembling. Repeatability is characteristic of the industrialization process carried out.

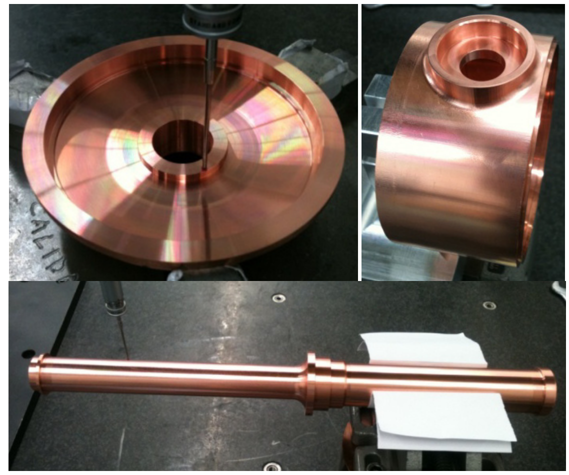

Figure 9: Different parts of the drift tubes for Linac4.

## CONCLUSIONS

Several goals were attained and valuable know-how was produced. Surface roughness (Ra) under 0.001 μm, and figure error better than 50 nm has been achieved.

Special tooling has been developed and manufacturing and industrialization of pieces for ultra high vacuum and intense electric fields are now within DMP and HTS's capabilities.

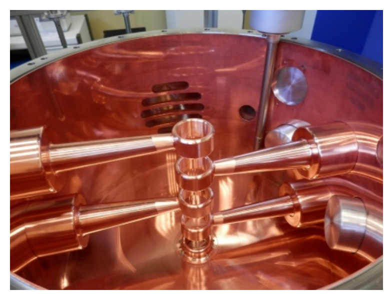

Figure 10: 5 Gap Buncher for CIEMAT.

Other kind of structures has also been performed at engineering and manufacturing levels as Submicrometric 2D Positioning Systems [6, 7], Phase Shifters [8-10] and bunchers [11] among other devices and assemblies. Engineering capability adds value to products, defining and designing them to simplify manufacturing processes while improving specifications and lowering costs. Since engineering is related to manufacturing and testing, both quality and delivery time are under control.

Better understanding of joining processes such as EBW, brazing and diffusion bonding allows offering these services in a transparent way in the near future.

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## REFERENCES

[1] A. Samoshkin, "CLIC two-beam module layout", CLIC Meeting (December 2010).

[2] F. Toral, P. Abramian, F. Aragón, J. Calero, D. Carrillo, J.L. Gutiérrez, A. Lara, E. Rodríguez, L. Sánchez, S. Doebert, S. Mathot, G. Riddone, A. Samoshkin, I. Syratchev, "Status of CIEMAT work on PETS," Nuclear Instruments and Methods in Physics Research A (2011), doi: 10.1016/j.nima.2011.05.026.

[3] L. Sánchez, D. Carrillo, D. Gavela, A. Lara, J.L. Gutiérrez, J. Calero, F. Toral, A. Samoshkin, D. Gudkov, G. Riddone, Development and testing of a double length PETS for the CLIC experiment area", Nuclear Instruments and Methods in Physics Research A 2014.

[4] L. Sánchez, J. Calero, D. Gavela, J.L. Gutiérrez, F. Toral, D. Gudkov, G. Riddone, "Design, fabrication and tests of the second prototype of the double-length CLIC PETS", IPAC 2014.

[5] L. Sánchez, J. Calero, D. Gavela, J.L. Gutiérrez, F. Toral, D. Gudkov, G. Riddone, "Design, fabrication and tests of the second prototype of the double-length CLIC PETS", IPAC 2014.

[6] F. Toral, C. Burgos, D. Carrillo, J.L. Gutierrez, I. Rodriguez, E. Rodríguez, S. Sanz, C. Vázquez, J. Calero, L. García-Tabarés, E. Adli, N. Chritin, S. Doebert, J.A. Rodríguez, "Design, manufacturing and tests of a micrometer precision mover for CTF3 quadrupoles," Proceedings of European Particle Accelerator Conference 2008, 1517-1519, Genoa, Italy (June 23-27, 2008).

[7] J. Munilla, "Design, manufacturing and tests of closed-loop quadrupole mover prototypes for European XFEL." International Particle Accelerator Conference 2011, Donostia-San Sebastián, Spain (September, 4-9, 2011).

[8] H. H. Lu, M.T. Wang, J. Zhwang, D. Wang, Y. Lu, B. Faatz, Y. Li, J. Pflueger, "A permanent magnet phase shifter for the European X-ray free electron laser," TESLA-FEL Report 2009-01.

[9] I. Moya, "Manufacturing and Testing of the First Phase Shifter Prototypes Built by CIEMAT for the European-XFEL", International Particle Accelerator Conference 2011, Donostia-San Sebastián, Spain (September 4-9, 2011).

[10] M. Altarelli, R. Brinkmann, M. Chergui, W. Decking, B. Dobson, S. Düsterer, G. Grübel, W. Graeff, H. Graafsma, J. Hajdu, J. Marangos, J. Pflüger, H. Redlin, D. Riley, I. Robinson, J. Rossbach, A. Schwarz, H. Weise, K. Tiedtke, T. Tschentscher, I. Vartaniants, H. Wabnitz, R. Wichmann, K. Witte, A. Wolf, M. Wulff, M. Yurkov (eds.), The European X-Ray Free-Electron Laser. Technical Design Report, July 2007.

[11] D. Gavela, P. Abramian, J. Calero, J.L. Guirao, E. Molina Marinas, I. Podadera, L. Sánchez, F. Toral, "Fabrication and tests of the rebuncher cavities for the LIPAC deuteron accelerator", IPAC 2014.