

THE COOL COPPER OPERATION LINAC DEMONSTRATOR PROJECT

S.M.Liuzzo*, C. Benabderrahmane, N. Benoist, P. Berkvens, P. Borowiec, R. Bourtembourg, T. Brochard, N. Carmignani, T. Perron, L. Carver, K. Andre, P. Colomp, A. D'Elia, M. Dubrulle, F. Ewald, L. Eybert, P. Falaise, D. Frichet, G. Giraud, C. Gonzalez Torres, G. Gatta, G. Chamblas, C. Lefevre, Y. Gouez, B. Joly, G. Le Bec, C. Maccarrone, D. Martin, M. Morati, H. Pedroso Marques, B. Pelissier, J.-L. Pons, Q. Qin, J.-L. Revol, B. Roche, T. Rozier, A. Sauret, K. Scheidt, V. Serriere, S. White, ESRF, Grenoble, France
G. Aymar, A. Dhar, A. Haase, Z. Li, S. Morton E. A. Nanni, W. H. Tan, SLAC, CA, USA
A. Latina, CERN, Geneva, Switzerland
D. Alesini, F. Cardelli, A. Giribono, C. Vaccarezza, G. J. Silvi, LNF, Frascati, Italy
M. Andorf, J. Maxson, Cornell University, Ithaca, NY, USA
P. Craievich, R. Zennaro
PSI Center for Accelerator Science and Engineering, Villigen, Switzerland

Abstract

The ESRF long term strategy for the injectors upgrade includes the possibility of a full energy 6 GeV linac. This linac is required to fit on the ESRF site leading to a maximum footprint of ~ 145 m. High gradient accelerating structure technology from SLAC was selected as the enabling technology to realize such a compact injector linac. The use of a photo electron gun will result in a small 6D beam phase space at extraction and the use of a pulse compression scheme to power SLAC structures will give a sensible cost reduction. The paper will introduce the Cool copper Operation Linac Demonstrator (COLD) project that has started at ESRF with the objective to realize a pre-injector linac and test all the enabling technologies for a high gradient cost effective, 6 GeV linac.

INTRODUCTION

The ESRF is presently considering a complete upgrade of the injectors to a full energy 6 GeV linac. This option is constrained by the limited space available (145 m). High gradient accelerating structure technologies are the only possible candidates to match this constraint. A linac injector would bring several advantages as detailed in Ref. [1]. The present ESRF storage ring (SR) injection efficiency in operation is in the range of 60-75 % depending on the filling mode (80 % is the best achieved). With the linac injector it would reach 100 % and would be transparent to users (no injection oscillations). In addition to this, the very small emittance will open the possibility of further upgrades of the EBS storage ring.

Since the ESRF does not pursue FEL applications, a full energy injector linac can profit from many simplifications, starting from the reduced repetition rate (4-10 Hz) and required beam properties (normalized emittance $\epsilon < 12$ mm mrad). Stringent requirements are set instead on reliability and maintainability of the injector.

The full energy linac parameters are within the limits of tested or available technology. The selected charge per bunch of 0.7 nC is at the limit of Cu photo-cathode. This value is required to limit the time needed for refills starting from zero current. A smaller charge per bunch could be acceptable if a higher repetition rate is chosen (uniform filling of 992 bunches would require 30 minutes, compared to 25 minutes needed to refill the most frequent mode 7/8+1). Else, the use of higher quantum efficiency cathode (e.g., Cs₂Te) will be possible, thanks to the brazing free technology adopted for the photogun [2].

THE COLD PROJECT

The COLD project will be the first validation at full scale (high power, 2 x 1m long structures) of the high gradient structures designed by SLAC [3] operated at cryogenic temperature enabling a compact linac design. COLD will be composed of an S-band photogun and two cryomodules each hosting two SLAC C-band distributed coupling accelerating structures. The first cryomodule and structures are provided by SLAC. The second cryomodule and accelerating structures will be designed specifically for the ESRF injector purpose. The schematic layout of the installation is shown in Fig. 1. COLD will be built in the next 4-5 years with the objective of validating the key technology for a high availability user facility. In particular, the experimental goals for the demonstrator will include:

- C-band 77 K high gradient technology:
 1. Reproduce expected accelerating gradient
 2. Evaluate performance degradation and failures in the presence of breakdowns. In the case of a distributed coupling accelerating structure, previous experiments and simulations indicate that the breakdowns are limited to only one cell (over 40 in a structure). This would lead to 4 MeV less energy in case of a breakdown rather than 80 MeV.
 3. Measure dark currents [4-8] to assess radiation hazards of a full energy installation.

* simone.liuzzo@esrf.fr

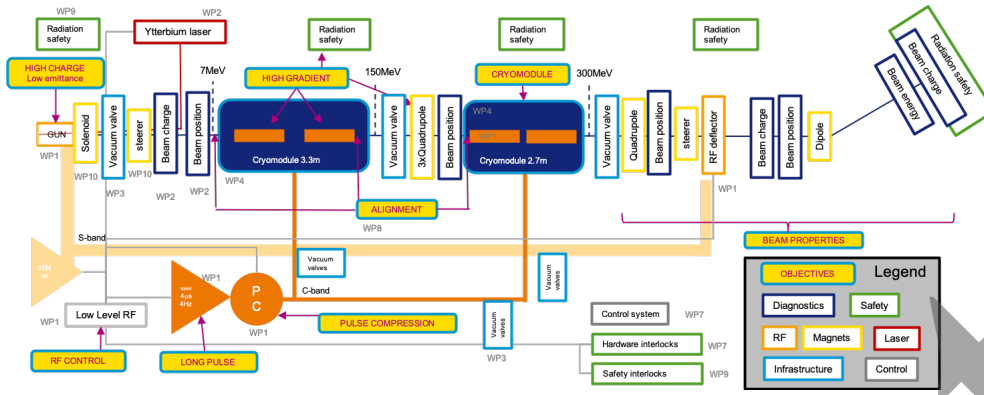


Figure 1: COLD project schematic layout. The Working Packages (WP) involved in each component are annotated.

- Evaluate reliability and maintainability for a user grade facility
- Measure vibrations induced by LN_2 flow
- Test the pulse compression applied to C^3 structures based on BOC (Barrel Open Cavity) technology developed at PSI [9] assuming long pulse (4 μ s) and low repetition rate (4-10 Hz) RF Units
- Evaluate shot-to-shot reproducibility in terms of size, length, energy spread, position at linac end and final energy
- Precision alignment strategies in cryogenic environment and inside the cryomodules.
- Gain experience at the ESRF with new technologies and train personnel on: C-band structures / modulators, laser, cryogenics
- Compact cryomodule design:
 1. Powering of 4 accelerating structures with one RF-Unit
 2. Synchronization of consecutive modules
 3. Evaluate the possibility to use cryoheads/cryocoolers
 4. Design accelerating structures dedicated to injection purposes (ex: larger iris)
- Experience on replacement and intervention procedures for cryocooled structures and cryomodule components.

Due to the relaxed beam parameters needed for injection in a storage ring (compared to FEL applications), bunch compression [10] and linearizers [11] are not needed. If the realization of a 6 GeV linac is found unrealistic or if it is discarded, the COLD project realization will anyway provide to the ESRF a new 300 MeV linac injector to replace the existing and aging 200 MeV one.

MAIN PROJECT COMPONENTS

A preliminary 3D drawing of the installation of the COLD project in the ESRF premises is shown in Fig. 2 taking in account the existing equipments and holes in the bunker wall. The photogun will be identical to the SPARC_LAB one [12], with movable solenoid and last laser mirror mounted in air.

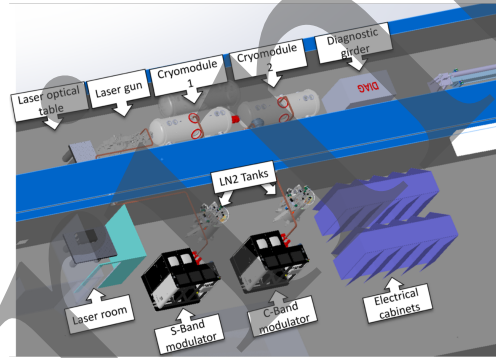


Figure 2: 3D drawings of the COLD project installation in the radiation safe tunnel available at ESRF. The possibility to install and remove the cryomodules in the remaining space is also presented (semi-transparent vessel).

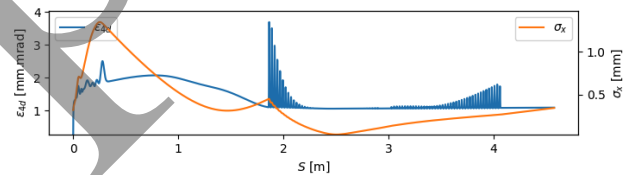


Figure 3: (Emittance (blue) and beam size (orange) for COLD assuming 700 pC charge, beam spot radius of $\sigma_r = 0.3$ mm, laser pulse duration of $\sigma_t = 2.79$ ps and a solenoid field of 0.29 T.

Beam Dynamics

The fields, beam size, and transverse emittance are shown for the first two structures of the COLD project without errors in Fig. 3 based on 6D multiparticle simulations in RF-Track [13] including space charge effects and short range wakefields. The initial particle distribution is obtained with the package *distgen* [14].

The expected beam emittance is $\epsilon_{h,v}^n = 1$ mm mrad with 100 % transport efficiency.

RF

The accelerating structures have been designed and are being built by SLAC for the C^3 collider. They feature a 4-fold symmetry and HOM damping slots. The waveguides are sufficiently long and flexible to allow movements of the

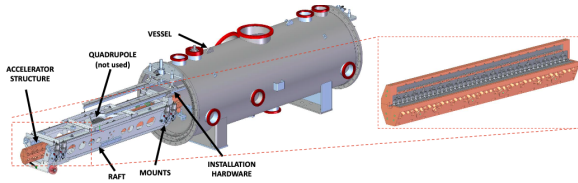


Figure 4: QCM assembly overview: vessel, accelerator structure, quadrupole (not used for COLD), raft, mounts, and installation hardware.

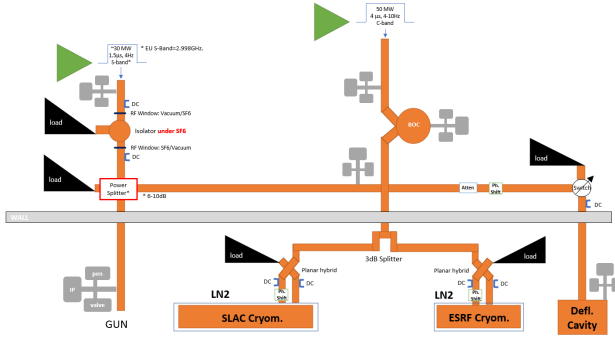


Figure 5: RF installation layout.

accelerating structures within the cryomodule up to ± 5 mm. The QCM (Quarter Cryo Module) developed and at SLAC for the C^3 collider will be used as the first cryomodule of the COLD linac. The vessel, accelerating structures and raft are shown in Fig. 4.

The overall RF distribution of the S-band line (feeding gun and deflecting cavity) and C-band line (which includes the BOC to feed SLAC accelerating structures) is shown in Fig. 5. A LLRF, similar to that in use at the SwissFEL [15], will be needed to synchronize and to control the whole installation: the S-band part at 2.998 GHz with that in C-band (5.712 GHz), and the laser system at 71.4 MHz.

A PSI Barrel Open Cavity (BOC) pulse compressor [9] will be used for COLD with the same characteristics of those operating at the SwissFEL [16]. This system will allow to operate the 4 structures of the COLD project with a single 50 MW RF-unit (4 μ s pulse length).

Diagnostics and Drive Laser for Photo Gun

The choice and implementation of the electron beam diagnostic instruments are based on the design beam parameters at the exit of the photo electron gun and the accelerating structures, respectively. The diagnostics will include instruments tailored and designed in-house for our needs (screens, Faraday cups and BPMs, spectrometer), as well as commercial instruments, such as for example the current transformers. All the needed diagnostic instruments will use well established technologies.

For a maximum of 700 pC of bunch charge from the photo gun, a laser pulse energy of at least 100 μ J on the Cu-cathode is required at $\lambda = 257$ nm. Taking into account losses along the photon beam transport line, a pulse energy of ~ 200 μ J

should be available from the laser. In order to preserve a short electron bunch length throughout acceleration, the laser pulse duration should be in the order of 200 fs to ≤ 10 ps. Diode pumped Yb-lasers with 4th harmonics generation can provide these beam parameters while being very compact and highly reliable. Such devices exist on the market and are used in similar installations (e.g., ARES at DESY, CTF2 at CERN).

Vacuum

The vacuum system will integrate different chambers and devices supplied by several institutes as well as components developed at the ESRF. This diversity comes with increased integration challenges as it is foreseen to maintain compatibility and re-usability with the EBS vacuum system components as much as possible. The vacuum system can be divided in 3 main areas, the beam transport vacuum chambers, the waveguides, and the cryogenic isolation vacuum, each with its own requirements. For beam transport a pressure $< 10 \times 10^{-7}$ mbar will ensure the required low level of beam losses. A low pressure on the wave guides will reduce the probability of breakdown. Finally, for the QCM isolation vacuum, a pressure of $< 10 \times 10^{-6}$ mbar will reduce the thermal losses of the LN_2 vessel. The main gas load is expected to be the thermal out-gassing of the vacuum chambers, as photo desorption will be minimal. To achieve the operating pressures it will not be required to bake out the vacuum chambers.

Alignment

The COLD assembly requires alignment tolerances on the order of 50 μ m (in view of the 6 GeV linac installation), which are tighter than those required for the ESRF storage ring, but close to those achieved in reality. To acquire the necessary expertise a dedicated small scale cryomodule will be built to test alignment procedures and fiducialization process in cryogenic conditions as well as monitoring of the structures movements during cool-down and warm-up. Direct visual inspection through glass windows on the QCM, Frequency Scanning Interferometry (FSI) and capacitive sensors are some of the techniques that will be used. The QCM raft will also be equipped with a Rasnik [17] system to monitor movements of the structures with respect to the raft holding them.

CONCLUSIONS

The COLD project will allow testing of the main components enabling the realization of a compact, < 145 m long 6 GeV linac. The project is started and will see the first installation taking place in January 2027 and first measurement (without beam) in October of the same year. Safety approval is being pursued and is on schedule. Budget is presently secured by the ESRF and additional human resources dedicated to the project are being hired.

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