STATUS OF THE ARES R&D PROGRAM

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Abstract

The ARES Superconducting Linac[1], as approved by INFN on the 15th of June 1990, together with the construction of a Φ-Factory (now called DAΦNE), asks for a three years R&D program to develop:
a) 500 MHz multicell SC cavities able to hold an accelerating field of 10 MV/m @ $Q_0 = 3 \cdot 10^9$;
b) a SC low emittance and high repetition rate injector.

The status of the program, accomplished in parallel with the completion of LISA, is given in the following.

I. CAVITY DEVELOPMENT

At present our program concerns the fabrication of prototypes of single and multicell 500 MHz SC cavities, using both bulk niobium and Nb coated copper[3]. Work on higher frequency cavities is also in progress and its development has been planned.

Bulk niobium cavities

Fabrication of a four-cell bulk niobium SC cavity is in progress, in the context of a collaboration with Italian industry (ANSALDO CO.). The process that has been developed is based on:

- deep drawing and spinning of the half cells,
- electropolishing of the cavity components,
- firing in a vacuum furnace at 700°C, inside a Ti box,
- EB welding from inside with a 90° deflected beam,
- final "metallographic" chemical treatment.

With respect to the chemical etching of the Niobium surface, we adopted the electrochemical etching (EP), mainly because of the Italian safety rules on waste disposal.

In order to test the overall cleaning procedure, we used an existing single cell, 500 MHz, Nb cavity, which was produced to develop EB welding procedures and related tooling. The results of the Q_0 vs E_{acc} are shown in Fig. 1, after three successive steps of the cleaning procedure, i.e.: electropolishing (EP), Ti box firing (HT) and final "metallographic" grain cleaning (MC).

The reported data have to be considered as promising since they were obtained in a vertical cryostat not equipped with magnetic shielding, the maximum field achieved being limited by a known defect in the equatorial region.

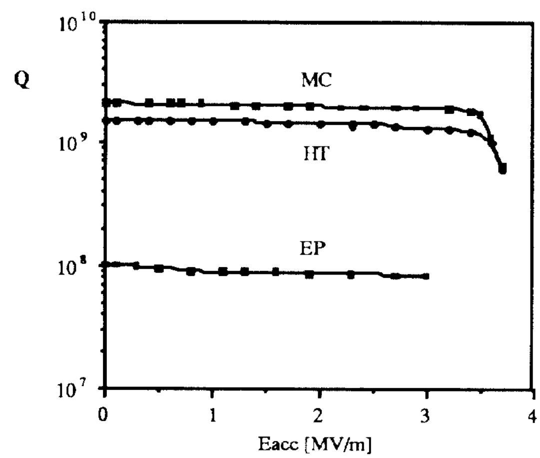

Fig. 1 - Experimental results of Q_0 vs E_{acc} for the first Nb single-cell cavity, after three successive steps of the cleaning procedure, i.e.: electropolishing (EP), Ti box firing (HT) and final "metallographic" grain cleaning (MC).

Copper, Nb coated, cavities

Following the CERN experience, we also started to develop the sputtering technique to coat Cu cavities with niobium, to profit from the good thermal conductivity of copper. Moreover this line opens the possibility to coat copper with different superconducting materials.

In the context of the collaboration with industry (ANSALDO CO.), the fabrication of a four-cell Nb coated cavity is in progress, in parallel to the realization of the bulk Nb one. The system adopted for Nb coating is the same developed at CERN, i.e. magnetron sputtering from a coaxial Nb tube placed inside the cavity.

Meanwhile the necessary equipment, both to weld cavities from the inside and to prepare the copper surface for Nb coating, have been acquired and made operational by industry.

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A first single cell cavity has been sputtered and tested[4]. While Q_o at low field is satisfactory ($4 \cdot 10^9$ & 4.5 K), the behaviour of the Q_o vs E_{acc} curve indicates that cleaning procedures and film quality were not yet optimized. A maximum field of 8 MV/m has been measured, Q_o being $5 \cdot 10^8$.

The mechanical procedure to fabricate the half cells for copper cavities is deep drawing instead of spinning. This method, originally planned also for bulk Nb[3], has been limited to Cu because of the large number of sheets which have to be sacrificed to get a proper set of parameters for the deep drawing and a proper shape of the molds. Once optimized, the results are more reproducible and the quality of the internal surface is better.

The first four-cell cavity has been EB welded and we expect to Nb sputter the cavity in June.

As a consequence of the collaboration with a second industry (Europa Metalli-LMI), the latter has developed the technology of hydroforming copper cells and several 500 MHz single cell cavities have been realized using ETP copper to optimize the procedure. A new set of cells, produced from Cu OFHC, is now completed and they will be Nb sputtered and tested starting from June.

Work on higher frequency cavities

Following the tradition of the group from Genova, which is involved in the ARES R&D program, we measured the limiting field of some 4.5 GHz cavity, built from Nb sheets by deep drawing.

These cavities, EB welded, were chemically polished (100 μm) and annealed at high temperature (2300 K) in a vacuum furnace having residual pressure of 10^{-7} torr.

An average accelerating field of 15 MV/m without any apparent electron loading, has been measured on a batch production of 3 cavities, with an average number of 5 test for cavity. The field limitation was always a fast thermal breakdown.

This work will be continued with single and multi-cell 3 GHz cavities, whose fabrication is in progress.

An activity on 1.5 GHz coated cavities is also planned.

II. SC LOW EMITTANCE INJECTOR

According to what was anticipated in ref. [1], one major objective of the ARES R&D Program is the development of a SC low emittance RF injector. In this context, at present we are mainly working on photocathode preparation and numerical simulation. We expect to be able to design the first injector prototype during next year.

The present status of the R&D program, concerning photocathodes and simulations is outlined in the following.

Photocathode production

In collaboration with an Italian company (SAES GETTERS), a special UHV chamber, for the preparation of alkali antimonide photocathodes, has been designed. A schematic drawing of the chamber is presented in Fig. 2.

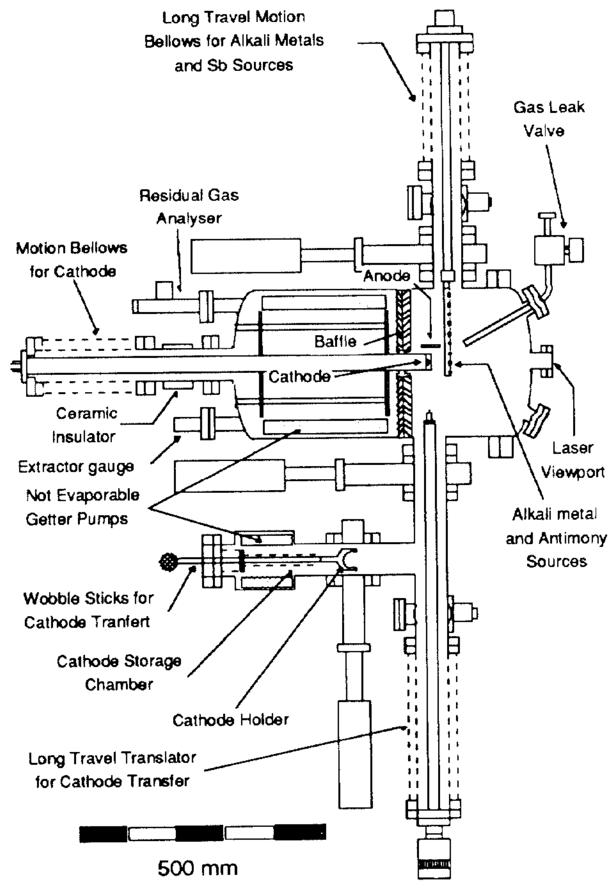

Fig.2 - Photocathode preparation chamber.

Because alkali antimonide cathodes are very sensitive to any reactive gas, 10 getter modules (SAES GETTERS-1250) are used in addition to a standard ion getter pump. The estimated ultimate pressure is in the 10^{-11} mbar range.

The alkali metals are produced by alkali metal dispensers[5] (based on alkali chromate reaction with zirconium). A new high temperature conditioning procedure of these sources ensures very low gas emission during alkali metal evaporation. Up to 8 different alkali metal sources can be assembled into the UHV chamber, enabling future developments on multi-alkali cathodes.

A load-lock system is used for introducing the source into the chamber and a special UHV transfer system[6],[7] has been developed for cathode transportation, both to surface analysis instruments or to the SC gun.

Numerical simulations

The design under study for the RF SC Gun is based on a 500 MHz 1-1/2 cell cavity[1], followed by a special single-cell resonator and a magnetic compressor[8-10].

Since in the SC Gun we expect a maximum electric field (peak) of the order of 30 MV/m, the adopted strategy is that to attain high beam brightness in two steps. The choice of a low RF frequency allows to accelerate rather long bunches and to magnetically compress them at the Gun exit once relativistic.

Because long bunches exhibit a substantial non-linear behaviour of the momentum gain with respect of the longitudinal position in the bunch, we add an especially shaped, fully decoupled and independently phased single-cell cavity downward the RF Gun cavity. This solution allows to employ cathode injection phases higher than the optimal one, while recovering the minimum value of the rms emittance and getting a more linear distributions in the longitudinal phase space[8], i.e. a more efficient magnetic compression.

The output peak current at the injector exit can be in the range of some hundreds of Amps with rms emittance of a few mm.mrad: that means a beam brightness comparable to that produced by high frequency, high peak field, RF Guns, together with a possible CW operation.

The results of the numerical simulations are summarized in Table I, where four different beams are listed, corresponding respectively to: VUV FEL (A and B), IR FEL and TESLA. The first two beams are quoted to better visualize the beam brightness enhancement produced by the decoupled cell. The parameters chosen for the TESLA beam correspond to a peak field of 50 MV/m on the cathode.

TABLE I - Numerical simulation results

		A	B	C	D
Bunch charge	[nC]	.5	.5	20	5
Laser spot (σ_r)	[mm]	2.	2.	3.5	2.8
Laser pulse length ($2\sigma_t$)	[ps]	20	20	40	70
Laser peak power	[kW]	8.7	8.7	175	87
Repetition rate	[Hz]	1000	1000	30	30
RF injection phase	[deg]	64	80	75	80
Output energy	[MeV]	7.4	3.8	6.8	6.1
Rms energy spread	[keV]	±17	±32	±170	±135
Rms bunch radius σ_x	[mm]	6.2	12.7	15.	16.9
Bunch length σ_z	[mm]	2.9	3.1	6.2	14.4
Rms divergence $\sigma_{x'}$	[mrad]	5.8	2.4	15.3	3.2
Rms emittance ε_n	[mm·mrad]	5.9	5.5	106	15
Peak current (no compr.)	[A]	19	18.5	350	35
Peak curr. (magn. compr.)	[A]	125	435	2750	640
Compressed σ_z	[mm]	.45	.13	.8	1.
Norm. bright.	[10^{11} A/m^2-rad^2]	.45	1.8	.03	.37

In order to understand the capability of the decoupled cell to recover the rms normalized emittance, ε_n, we studied the behaviour of the total transverse momentum transfer induced by the decoupled cell[11]: as sketched in the following, the momentum transfer is found to be dependent on the injection phase and the decoupled cell acts as a RF lens.

In fact it is well known[12] that, at the gun exit, the transverse momentum of an electron, leaving the gun at a phase ϕ (with respect RF) and at a radius r, is given by:

$$p_r = \alpha k \cdot r \cdot \sin\phi \ [\text{mc unit}],$$

where: $\alpha = E_o/(2kmc^2)$, $k = 2\pi/\lambda_{RF}$ and E_o is the peak field on the cathode.

When the average exit phase, $<\phi>$, of the bunch is $\pi/2$, the increase of ε_n due to RF field is minimum. Away from the optimal value the RF contribution to ε_n is given by:

$$\Delta\varepsilon_{RF} = \alpha k <x^2> \sqrt{(\Delta\phi^2)} |\cos<\phi>|$$

where $\sqrt{(\Delta\phi^2)}$ is the rms bunch length [RF deg].

To recover the minimum emittance condition, a device able to induce a transverse momentum transfer strongly correlated to the injection phase is therefore used.

In a single cell cavity, for $\beta \approx 1$ particles, travelling slightly off axis, at a radius r, the transverse force produced by the accelerating TM_{010} mode can be written as:

$$F_r = e(E_r - cB_\theta) = -(er/2c) \cdot dE_z/dt$$

where $E_z(z)$ is the on axis electric field. Moreover, the transverse momentum transfer at the cavity exit is:

$$\Delta p_r = -\frac{e}{2mc^2}\int_0^t r\frac{dE_z}{dt}dt = \frac{e}{2mc^2}\int_0^L \beta_r E_z dz = \frac{\beta_r}{2mc^2}\Delta V(\phi)$$

where: $\beta_r = p_r/p_z = \text{const.}$, L is the cell length and $\Delta V(\phi)$ is the electron energy gain in the cell.

Considering now a divergent beam injected into the cell, as is the case for bunches leaving the gun, the previous equations allow to achieve a phase vs transverse momentum correlation that compensates the extra-correlation present at the gun exit when injection phases different from $\pi/2$ are used.

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