RF SC Activities at Frascati INFN Laboratories.

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I. INTRODUCTION

SC RF a ctivities at Frascati INFN Laboratories are centered on the SC linac LISA and its application to the implementation of an FEL.

Besides this, in collaboration with Rome II University, the assembly of a sputtering test facility is in course at the INFN section of that University.

The activities connected with TESLA are described elswhere in these proceedings(see report on Tesla cryostat in Future Developments section).

II-STATUS OF THE LISA LINAC

The 25 MeV, 2 mA, SC linac LISA [1], equipped with 4-cell, 500 MHz superconducting cavities, has now been completely assembled and its commissioning is well advanced.

The beam has been transported through the 1 MeV injector to the entrance of the SC accelerating section.

Three of the four cavities have been partially reconditioned with RF power, reaching on the average an accelerating field of 3.5 MV/m, with quality factor Q_0=1.5x10^8 limited by electron loading[Fig.1]; the low field Q value is of the order of 2x10^9. Peak field is not limited by quench; in pulsed operation a peak of about 5 MV/m has been obtained. Further conditioning is required to reach the design goals.

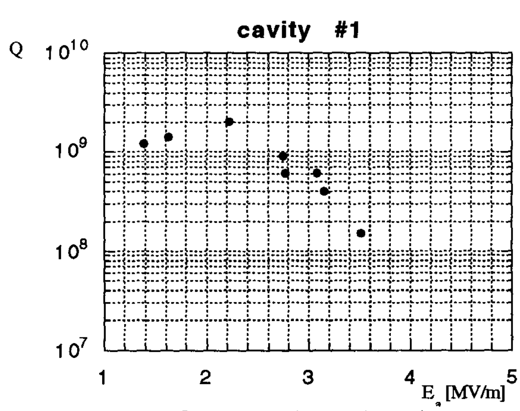

Figure 1. Q vs. E_{acc} for cavity n.1

Progress has also been made in the construction of the transport channel to the FEL experimental station. Magnetic elements, including the undulator, are in place and ready for alignment and the vacuum chamber has been delivered.

Optimization of the parameters of the 1 MeV injector has proceeded by maximizing the current transported through the 180° bending arc and minimizing the energy spread observed on the 1 MeV spectrometer.

Table 1
Beam transport measured data

Gun voltage	90 KV
Gun current	120 mA
Chopping angle	90 deg
Pulse length	1 msec
Avg. current after capt. sect.	2 mA
Energy spread	2%
Avg. Current after 180° arc	1 mA

The beam transport measured performance is summarised in Table 1.

The transverse diagnostics, consisting in fluorescent targets and strip-line electrodes, is working satisfactorily.

Oxidized Aluminum targets have given good results, avoiding the adverse effects of charge build-up observed with ceramic targets at low energy and high charge levels.

Optical transition radiation has been observed on a polished Aluminum target at 1 MeV. It is intended to use this technique for accurate diagnostics of the beam accelerated by the cavities at higher energies , where the observation is easier..

Three of the bulk Nb cavities have been partially reconditioned after several months of idleness under vacuum created by ion pumps..

The RF was pulsed with 30% duty cycle and 1 Hz repetition rate. In a few hours the field reached 2 MV/m with unloaded Q factor ≈ 10^9. Above this threshold a steep decease of the Q(E) curve was determined by electron loading. A supplementary RF conditioning (≈ 24 hrs) shifted the knee to about 3 MV/m. The conditioning was not pushed further due to lack of time.

In some of the cavities the apparent field limit for electron emission onset (evidenced by X ray emission) was somewhat lower than 3 MV/m .This could be due to unflatness of the field distribution, producing higher peak fields in some cells. To check this we have measured the dispersion curves of the four cavities and compared them with the theoretical one. Two of them are shown in Fig.2.

The cavities with mode frequencies farther away from the theoretical ones are in fact those with lower field thresholds.

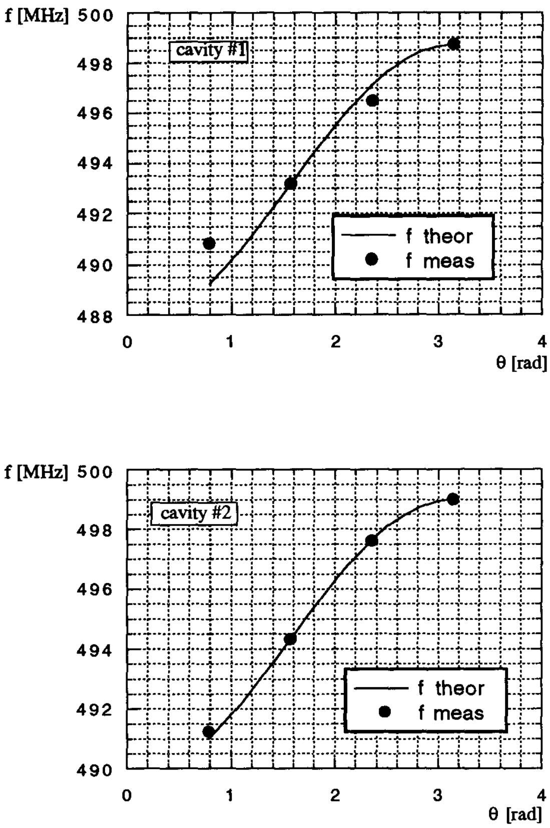

Figure 2. Dispersion curves of cavities 1 and 2.

The Q factor has been determined by measuring the variation rate of the level of liquid helium in the bath.

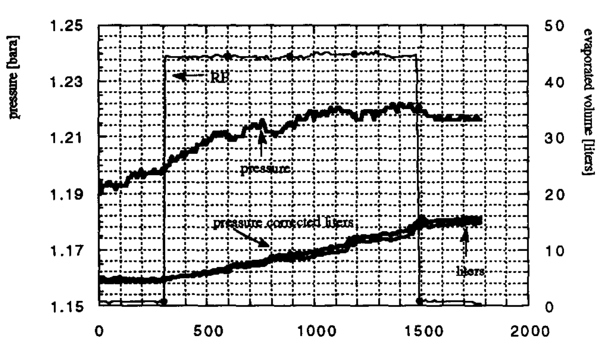

Figure 3.Evaporated LHe liters vs. time

Using the built-in heating resistors on the LHe container, we first introduce a known amount of power, much larger than static losses, in the cryostat and with the refrigerator in automatic operation wait until an average equilibrium state is reached. Under such conditions the LHe inlet valve performs small oscillations around its average position. Once the latter position has been determined, the valve is blocked there manually. The fixed LHe input then almost exactly compensates the overall heat input and the level remains sufficiently constant for tens of minutes. We can then switch on the RF and measure the liquid level fall rate and from this evaluate the dissipated RF power. The Q factor is then determined from the value of the RF electric field, measured through a calibrated probe.

The method has been improved by taking into account pressure variations. In Fig. 3 we show the behaviour of pressure and a corrected level variation curve. A detailed description of these measurements is in the literature [2].

The mechanical tuning system has been tested on a cold cavity. The electronics consists of a phase detector that compares the incident voltage with the transmitted one from the field probe. The ouput from the phase detector, above a given threshold, drives the step-motor that moves the mechanical actuator. On the phase detector signal, in addition to some drift, we observe fluctuations due to cavity vibrations with frequencies in the range of several tens of Hz, that fall within the cavity bandwidth (≈ 100 Hz). These fluctuations are filtered out before the tuning actuator so that only slow (few Hz) drifts are corrected. The residual fast phase and amplitude variations of cavity field are counteracted by electronic loops .

III-THE SPUTTERING FACILITY

In the framework of the ARES project and as possible application for TESLA project, we are assembling, in the 2nd University of Rome, a system to study the deposition of Nb film on TESLA type copper cavity. Magnetron sputtering to coat accelerating cavities with superconducting film was developed at CERN for 500 MHz cavities, 3 times larger than TESLA cavities; while it's relatively easy to scale the technique up to larger cavities (as for instance to the 350 MHz LEP cavities) there are some difficulties to scale it down, particularly as concerns the coils located on the inside of the cathode used at CERN to stabilize the discharge, unless small permanent magnets are used that do not allow full control over all discharge parameters. A possible solution is to put the coils outside the cavity in a magnetic bottle configuration.

To clarify the the philosophy of the design of our apparatus a brief review of the sputtering technology is proper.

Sputtering is a well known and useful technique for coating RF copper cavities with superconducting thin films. In the sputtering process [3] one ejects source material from the cathode in vapor phase by bombarding the surface of the cathode with ions of sufficient energy (at least 30 eV), in our case Argon ions accelerated by an electric field; the ejected atoms condense on the wall in front of the cathode forming the thin film.

There are different sputtering configurations of which the simplest is the diode one. In this configuration the cathode is negatively polarized with respect to grounded copper substrate electrically connected to the anode. Some of the problems of this configuration are film contamination due to impurities coming from the pumping system, unavoidable at high working pressures and from the chamber wall degassing due to discharge heating, and mechanical complications in case of sputtering inside a cavity (first CERN approach [4], [5]).

Low pressure is therefore mandatory but to obtain reasonable sputtering rates at low pressure the ionization degree of sputtering gas has to be increased by increasing the ionization efficiency of electrons in the discharge. To accomplish this the electrons active path must be restrained to the vicinity of the cathode, for instance superposing a perpendicular magnetic field on the electric one so as to prevent electrons from losing their energy through collisions at the anode rather than through ionization.

This is the present sputtering system configuration used at CERN to coat 350 MHz copper cavities with Nb films [6]. The magnetic field necessary to confine electrons is produced by a coil placed inside the cathode; the coil is moved in steps along the cavity axis to achieve a uniform coating.

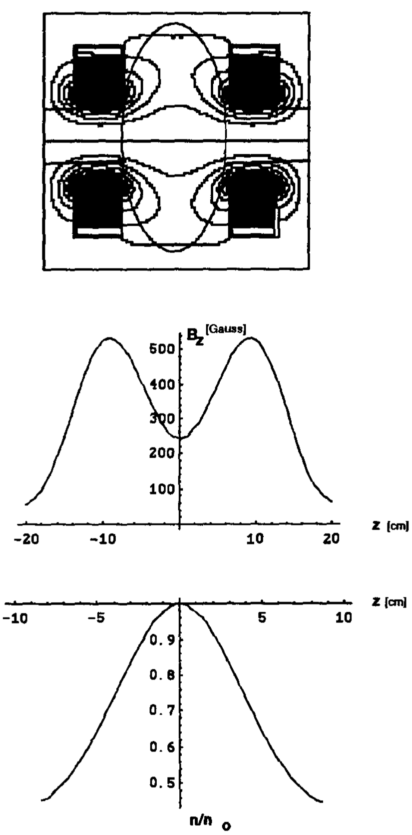

Figure 4. a) Magnetic mirror field lines
b) Longitudinal magnetic field intensity on cathode surface
c) Normalized longitudinal plasma density

The RF frequency selected for TESLA being 1.3 GHz, the cavities are 3 times smaller than those on which the CERN technique has been optimized. In face of the difficulty of scaling down the CERN technique it has been decided to investigate two alternative configurations. a) Small permanent magnets (typically Samarium-Cobalt alloy)) are used that fit comfortably inside the cathode. The latter however produce a fixed magnetic field configuration that limits the range of the discharge parameters variation. b) An alternative way of confining the discharge is to use a magnetic mirror field configuration. The latter is well known from plasma physics and refers to the fact that charged particles spiraling around a static magnetic field line will be reflected by a region of stronger field due to the adiabatic constant of the motion $\mu = mv_\perp^2 / 2B$. A magnetic mirror can be obtained, as it is in our design (Fig.4a) by means of two coils placed on the outside of the cavity cut-off pipes. The field shape is obtained by suitable soft iron poles.

The field has a minimum (~ 200 Gauss) at the center of the cavity and a mirror ratio (that is a measure of the trapping efficiency) $B_{max.}/B_{min.} = 2$ (Fig.1b).

Doing so we expect to trap electrons and ions very close to the center of the cathode. In such a configuration in fact charges are subjected to an axial restoring force $F_z = -\mu(dU(z)/dz)$, where $U(z) = \mu B(z)$ is a potential well proportional to the magnetic field strength. Charges are confined if the condition $(v_\perp / v) \geq \sqrt{(B_{min} / B_{max})}$ holds. The charge density longitudinal distribution is given by

$$n(z)/n_{min} = e^{-\frac{U(z)-U_{min}}{KT}}$$

and is shown in Fig.1c for the worst case $(v_\perp / v) = 1/\sqrt{2}$.

The sputtering system that we are assembling is schematically shown in Fig.5.

It can accommodate different stainless steel TESLA type cavities on the inner walls of which, along the whole cavity profile, copper and sapphire samples can be fastened that allow studying the characteristics of the film over a wide portion of the surface. We plan to characterize the Nb film through RRR and T_c measurements, Auger, SEM and X rays analysis. Plasma characteristics will be studied using Langmuir probes.

The system is evacuated by an ultraclean pumping group consisting of a 4 m^3/h diaphragm pump for the primary vacuum and two cascaded turbo molecular pumps (pumping speed respectively 180 l/sec and 520 l/sec) one of which on magnetic bearings. A very good compression ratio for hydrogen, good ultimate pressure (~10^{-10} mbar) and total absence of hydrocarbons is obtained.

The system is equipped with a residual gas analyzer (RGA) to study the ultimate pressure gas composition, and to monitor the percentage of gas produced during sputtering, notably hydrogen, that damages the film structure if it exceeds a certain threshold. To use the RGA while sputtering, in a relatively high operating pressure (~10^{-3} mbar), we need differential pumping; the RGA therefore communicates with the cavity through a 0.6 mm diaphragm and it is equipped with another pumping system that produces a 3 order of magnitude pressure drop through the diaphragm.

The cathode consists of a vacuum tight stainless steel tube (17 mm inner diameter) surrounded by a niobium liner (20/24 mm inner/outer diameters). The liner is an high purity Nb tube (RRR value better than 100) without welds. The stainless steel tube is also equipped with an inner support to hold and center 7 SamCo permanent magnets (small cylinders 8 mm diameter 16 mm long) cooled by a liquid freon circuit sized to handle about 2 KW of power. Preliminary tests to optimize discharge parameters will be carried out both with permanent magnets and with the magnetic bottle field configuration.

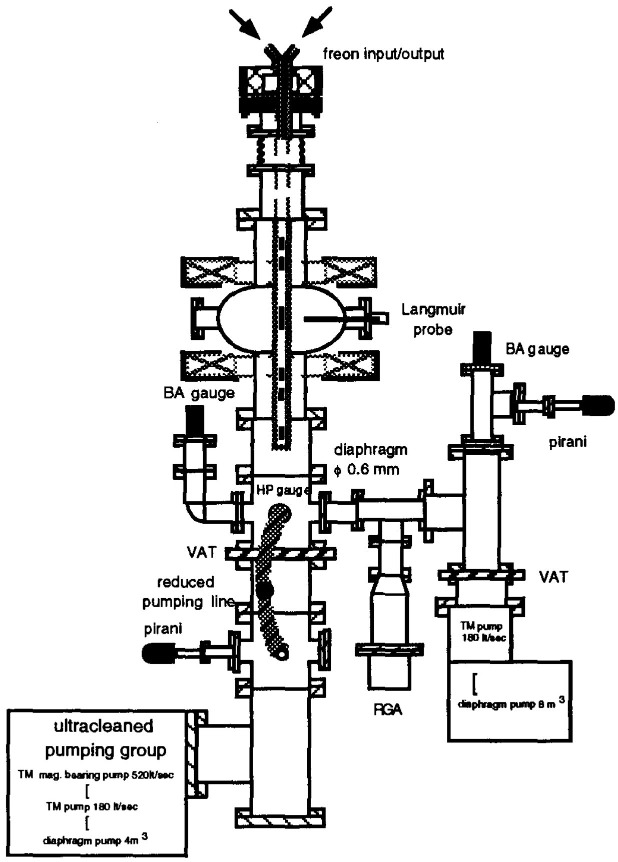

Figure 5. Sputtering system scheme

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