REPORT ON SUPERONDUCTING RF ACTIVITIES AT CERN FROM 2001 TO 2003

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Abstract

The main project on superconducting RF at CERN in the period from 2001 to 2003 has been the 400 MHz SC system for the LHC. Five modules, each containing four single-cell Niobium (Nb) sputtered cavities, have been assembled and low power tested at room temperature and at 4.5 K. Production of the first four power couplers has been delayed but high-power tests should start on the first module this autumn. A small program of R&D is maintained on the SPL. Both the $\beta = 0.7$ and $\beta = 0.8$ cavities have been high-power tested up to nominal field without particular problems. A detailed characterization of the cavity mechanical resonances is going on and some preliminary results are presented. A computer code has been written to predict the effects of Lorentz detuning and microphonics on the stability of the RF feedback loops in SC linacs where several cavities are driven by a single high power source. Fast ferrite phase shifters are being developed to allow the decoupling of the feedback loops of individual cavities attached to the same klystron. Several collaborations, e.g. SOLEIL, PACO and S3HC, have successfully achieved their objectives. The collaboration established with Cornell to develop a 200 MHz SC cavity has not yet led to the desired level of performance. The R&D program on 1.5 GHz is continuing. Based on an optimised electropolishing process for surface preparation, the study is at present focused on the effect of Hydrogen (H_2) on the Nb films' RF performance.

SUPERCONDUCTING MODULES FOR LHC

Two proton beams circulating in separate vacuum chambers will be accelerated by a superconducting RF system. Each beam will need 8 MV of RF voltage at injection, ramping up to 16 MV during collisions at 7 TeV. At the chosen frequency of 400.8 MHz (twice the RF frequency of the SPS), and using single cell cavities to keep the power transferred through the power coupler at a reasonable level (< 300 kW), each cavity will deliver 2 MV of RF voltage, with a nominal gradient of ~5.5 MV/m [1]. This gradient is relatively low for a cavity at this frequency and gives a good margin for reliability of operation. Indeed, all the 21 cavities produced (16 to be installed and 5 spares), perform better than specified ($Q_0=2\cdot10^9$ @ 5 MV/m). The cavities have been installed in fours in their cryostats to reduce the static losses. Five modules are ready to receive the last component, the power coupler, and to be conditioned up to the nominal power. With this aim in mind, the CERN SM18 installation has been upgraded to test the cavities in an LHC-like environment. We have changed the power supply, installed a series LHC 300 kW klystron, and renewed the control system to reproduce the system we will install in the LHC. The installation of the cavities is in fact scheduled at the end of 2006, only six months before the first beam. For this reason we must be able to test the whole system before the installation.

The program of test has been delayed by difficulties in the production of the power coupler. The fabrication process of the ceramic and the brazing procedure were at the origin of micro cracks of the ceramic leading to leaks and breaking of the ceramic at high power. All the manufacturing procedures have been re-analysed and changed when necessary together with small geometry changes. This has led to a finally successful conditioning, up to 500 kW in full reflection, of four couplers on the room temperature test cavity. The couplers have been mounted and baked out on the first module and are going to be conditioned from now to December up to 300 kW in full reflection. The first prototype of the low-level control electronics will be ready by spring 2004, when we will start to work in parallel to debug the low-level control system while conditioning the remaining modules.

A considerable effort has been put into the work of integration and preparation for the installation. In the LHC the Liquid He distribution system (called QRL) is adapted to the needs of the different SC magnets, due to their enormous numbers (>1600) with respect to the cavities (16). The drawback for the cavities is that the He pressure in the cold return line of the distribution system can rise up to 20 bars in case of quenches in the magnets, while the cavities, built with relatively thin (3.3 mm) copper sheeting, can only withstand a few bars before buckling. A safety level of 2 bars in the He vessel has been fixed to avoid plasticization of the cavities and storage of mechanical energy in the structure. In order for the pressure to remain below that limit, two systems are foreseen on each installed module: connection to a Warm Recovery Line (WRL) and safety valves.

Connection to Warm Recovery Line

A connection to the WRL, a return line for He gas at 300 K kept at 1100 mbar during normal operation, has been foreseen in the LHC tunnel. A pressure regulating valve will release He gas evaporated in the module to the WRL when the pressure in the module rises over 1600 mbar (the nominal pressure during operation is 1350 ± 15 mbar). This back-up connection to the refrigerator will work either in parallel to the normal return line or alone (if the QRL pressure is over 1600 mbar).

Safety Valves

If the refrigerator fails, a general pressure increase beyond the allowed value of 2 bars will occur in all the distribution systems, both Cold and Warm. In this case safety valves releasing He in the atmosphere are needed. The diameter of the safety valves has to be dimensioned for the worst case of sudden degradation of the insulation vacuum in the cryostat. In this case a heat transfer of ~5000 W/cm^2 will suddenly be seen at the surface of the He vessel, requiring a release valve of ~1400 mm^2 cross section to stay below 2 bars (required diameter 42 mm). We will install two such valves to have a safety margin of about 2. Leak-tight mechanism valves have been chosen to insure that they will be able to close again once opened. This will prevent problems due to sudden input of humidity from the valve opening. This is the main drawback of rupture disks and the reason we decided not to install any.

R&D

R&D was focussed on two major items: cavities for the SPL and the research of the parameters influencing the quality of Nb films on bulk copper.

For the SPL[2], two prototype cavities $\beta = 0.7$ and $\beta = 0.8$ have been successfully high power tested, reaching the nominal field for the SPL without problems. On the $\beta = 0.7$ cavity we are presently measuring the frequency and damping factor of the longitudinal vibration modes in order to investigate the stability of the final machine. Here we have run simulations with the computer code written to simulate linacs where several cavities are driven by one klystron. The result of simulations performed with estimated values suggests that above a certain limit, the cavities start to oscillate in a chaotic way, leading to instability of the control loop that can only regulate the sum of the vectors representing the voltage in each cavity, and not the single cavity voltages [3].

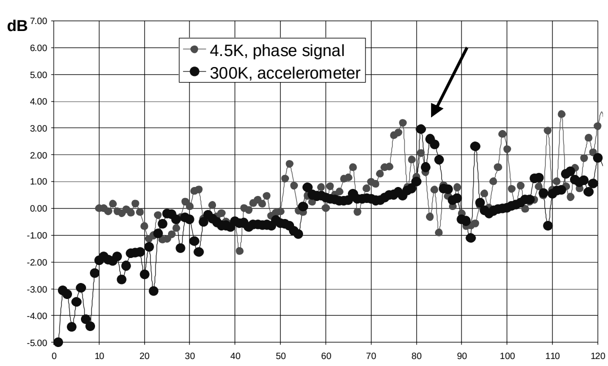

Figure 1: Mechanical response of the β=0.7 cavity to longitudinal excitation: the main resonance, pointed by the arrow, is around 77 Hz at 4.5K (81 at 300K).

Two ways of reducing this risk are followed. One is to measure the natural frequencies of the existing cavities to ensure that no harmful resonance mode exists. The second is the development of fast amplitude and phase modulators based on high-power ferrite phase shifters, to be able to adjust the field (amplitude and phase) in each cavity independently.

For the first, the preliminary data shown in fig. 1, compare the mechanical transfer function measured at 300 K with an accelerometer measuring the longitudinal oscillations, and the Frequency Response Function measured using as output signal the phase of the RF field with respect to the input power modulation at 4.5 K on the $\beta = 0.7$ cavity. The diagrams converge on the main resonance around 77 Hz with a Q factor of about 15. This resonance is not considered to be a problem for SPL operation. We plan to measure the response of the accelerometer also at 4.5K.

The fast phase shifters (fig.2) are being built by AFT GmbH and will be high-power tested (up to 300 kW) at CERN by the end of the year.

Figure 2: Fast ferrite phase shifter (courtesy of AFT GmbH).

For the research on the properties of Nb films on copper bulks, the main parameter studied during this period was the influence of H_2 on the Nb film RF performances. For the detailed results see ref. [4].

COLLABORATIONS

SOLEIL

A collaboration was established among CEA-Saclay, ESRF, Synchrotron SOLEIL and CERN to install the prototype two-cavity module built by CEA and CERN in the ESRF synchrotron and test it with a real beam. Though difficult in the realization since no cryoplant for the liquefaction of evaporated He exists at the ESRF, the test has been fully satisfactory, with the acceleration of 170 mA of beam stored in the ESRF ring. The details of this test are presented in refs. [5,6].

S3HC

CERN built in collaboration with CEA-Saclay, PSI and Elettra-Trieste two 3rd harmonic passive cavities for the increase of beam lifetime in the PSI and Elettra rings and the increase of their stability limits. Both cavities, designed and assembled by CEA, reached their goals. The detailed descriptions of the projects can be found in refs. [7,8,9].

PACO

We built in collaboration with INFN-Genova, a massive niobium prototype cavity to be used for the detection of gravitational waves at frequencies around 10 kHz. The cavity was built using high-purity (RRR 250) massive niobium, formed by spinning and electron-beam welded. The geometry of the cavity is made by two spheres connected by a small vacuum tube. Though chemically treated by BCP and rinsed with low-pressure (<6 bar) high-purity water with some difficulty due to the small apertures, the cavity reached a Q_0 of nearly 10^{11}. A more extensive description of the project and the results are presented in ref. [10].

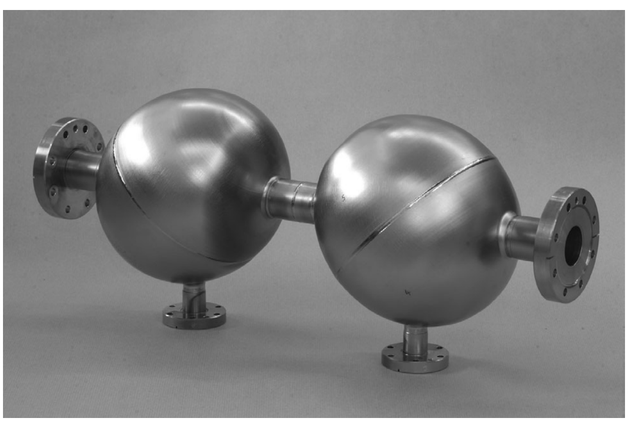

Figure 3: PACO, the 633 mm long superconducting resonator for the detection of gravitational waves.

200 MHz single-cell cavity

The 200 MHz cavity designed and built at CERN in Nb/Cu in collaboration with the Cornell University has been tested several times at Cornell with only partially successful results. The Q_0 at low field (<5MV/m) was in good agreement with the expected value (> 10^{10} @ 4.5K), while at high field (>10 MV/m) the Q value drops more than expected, with a performance that is not yet satisfactory for real applications. Further attempts will be made to increase the performance. A full description of the project and the test results can be found in ref. [11].

CONCLUSIONS

Cavities for LHC are ready to be tested at high power. The first module will be tested before the end of the year. R&D continues in two frameworks: the SPL, with investigations on mechanical stability of the cavity and stability of the feedback loop on a klystron feeding several cavities, and the research of the factors influencing the performance of Nb films sputtered on Cu. Several collaborations successfully achieved their objectives.

ACKNOWLEDGEMENTS

We are grateful to the technical staff at CERN and in the different laboratories as well as in private companies who with their commitment enabled us to achieve all the results described in this paper.

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