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LONG TERM PERFORMANCE OF THE SUPERCONDUCTING CAVITIES OF THE SACLAY HEAVY ION LINAC

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1. Introduction.

The Saclay heavy ion superconducting linac has been in operation at full energy since mid 1989. The 50 independent superconducting helix resonators have now accelerated beams for more than 20000 hours since then. We analyze here the long term performance of the linac, insisting on the specific aspects of superconducting R.F. technology.

2. Linac layout.

The linac is made of 48 accelerating resonators distributed in two accelerating legs. Each leg consists of 3 cryostats housing each 8 accelerating helix resonators (figure 1).

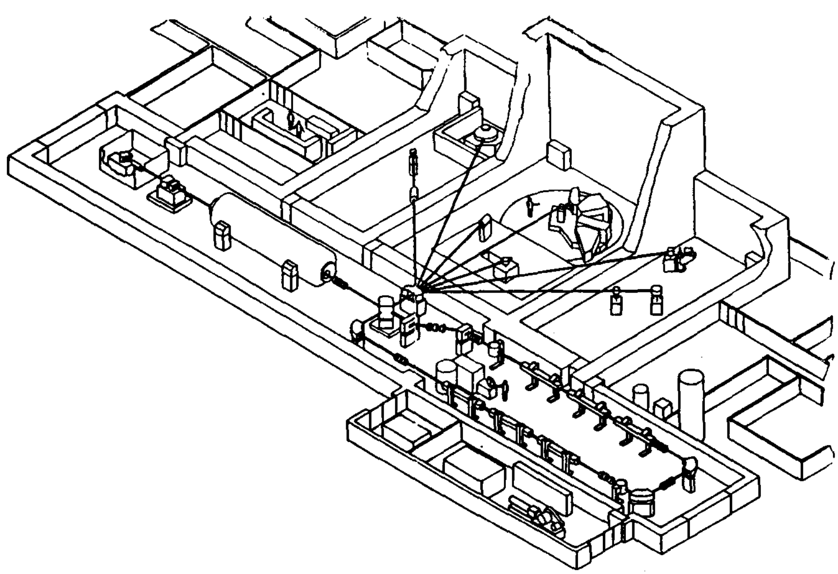

Figure 1. View of the machine. The 9MV FN Tandem injects beam into the 6 cryostats folded linac. Each cryostat contains 8 superconducting resonators. Beam is directed to one of 7 experimental beam line with a switching magnet.

In addition, two helix resonators in their own small cryostats are used as high energy beam bunchers at the beginning of the linac and at the input of the second leg of the accelerator. The latter is needed because a sizable time spread is induced by energy dispersion in the long drift (more than 20 meter) in the 180° bend at the output of the third accelerating cryostat. Two solenoids are used inside each cryostat to compensate for the defocusing effects of the resonators in the transverse phase space; outside the cryostats focusing is done with more conventional quadrupoles. A switching magnet dispatches the beam to the 7 experimental lines.

3. Resonators.

Our helical resonators are described in detail in refs 1 to 3.

We just show here a drawing of the full-wave (135 MHz) resonator design (figure 2) The accelerating field distribution is similar to that of a three gap resonator such as the Argonne split ring. We use also half-wave resonators at 81 MHz with a much slower variation with mass of the transit time factor, like in two gaps resonators such as the Quarter Wave Resonator (Q.W.R.).

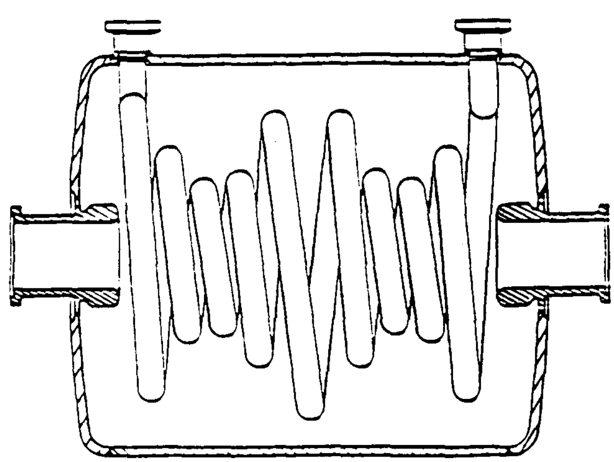

Figure 2. Full wave helix resonator. Overall length is 33 cm

Helices have a very poor mechanical stability because of their spring-like shape and indeed the static frequency shift (shift in frequency due to the deformation of the helix at high field by the electromagnetic forces) of our resonators is very high as compared with that observed in other designs, for instance in QWR resonators where it is of the order of a few (or a few tens) of Herz. We were thus forced to use drastic measures to reduce the ambient mechanical vibrations (described in ref 1) and to use a Voltage Controlled Reactance (V.C.X) on each resonator to lock the electric field phase to that of the master oscillator (see ref 1 and ref 3 for earlier studies). P.I.N. diode failures are rare (on the average 1 per month) although 300 diodes are used in the 50 V.C.X (1 for each cavity). The V.C.X can handle vibration induced frequency shifts of about 1 kHz in the case of the three gaps resonators, and slightly less for the two gaps. This is generally enough in most cases. Sometimes, though, some cavities cannot be controlled at all, generally because of instabilities in the helium flow, and slight changes of the cryogenics parameters such as valves openings have to be done to bring the situation to normal. Some resonators are also sensitive to the speed level of the refrigerator reciprocating wet expander. Despite these occasional problems, the out of lock time percentage, due to vibrations alone and not to equipment failures or cavity thermal breakdowns, is less than 1% when averaged during several hours.

4. Cryostats.

The cryostat design (figure 3) is such that insulating vacuum and beam vacuum are separated.

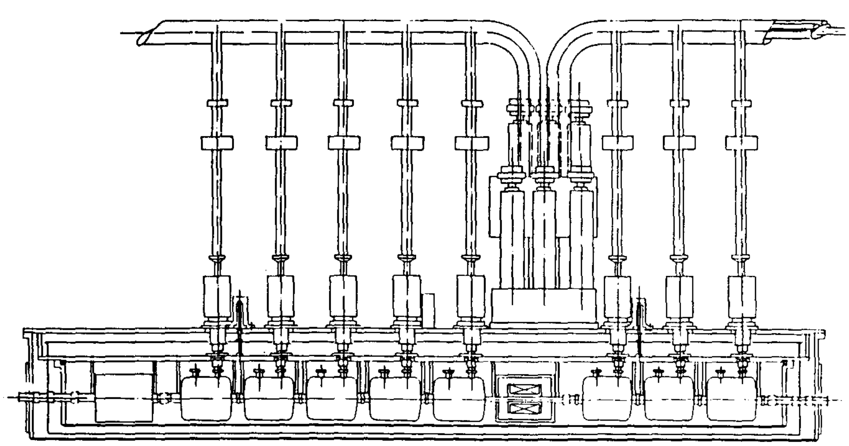

Figure 3. Helium cryostat with 8 cavities and 2 superconducting solenoids

This is the design applied to all present electron superconducting linacs but seldom used in heavy ion accelerators. The obvious advantage of this separation is that it insures a very clean beam vacuum but the unavoidable drawback is the necessity of having leak-tight RF feed-throughs at 4K. This requirement is sometimes difficult to achieve reliably, with present technology, as most superconducting electron resonator group have experienced, and we were also plagued by this problem as described later in this paper.

The resonators are shielded with high permeability alloy (Conetic AA) to reduce the magnetic field induced by the superconducting solenoids. This is enough to lower the remanent field of the solenoid iron shield to less than 100 milligauss at the resonator surface but insufficient to protect against the fringe fields when the solenoids are operating. When cooling to 4K, some magnetic flux vortices are then created on the external envelope of the resonator by the remanent field, but the internal field is weak and thus the helix is protected despite the fact that in our cooling procedure we maintain its temperature above T_C by closing the input helium valve on the helix circulation, and by injecting an RF power of about 10 watt until the envelope is fully immersed in liquid helium (to prevent gases to condense on the helix surface). After this cooling procedure, the Q value of the resonator stays high because most of the electromagnetic energy is located near the helix and not at the surface of the external envelope.

A sometimes invoked effect to explain the lowering of the Q value following thermal breakdowns of superconducting resonators is thought to come from the fact that a small fraction of the superconducting material becomes locally normal-conducting during the thermal breakdown, allowing the magnetic field to reach the RF surface and to stay there (in flux vortices if they are blocked by crystalline impurities) after recooling.

This effect cannot happen with our cavity design in normal operation, even with the solenoids at high fields, since no breakdown ever happens on the outside envelope where the R.F. electric and magnetic fields are low.

5.Beams.

Every year the machine delivers beams to experimental areas during 3 periods of 8 weeks each separated by maintenance and setup periods. This brings the total beam time to about 4000 hours per year. The setup time includes the starting of the refrigerator, if it was stopped during summer overhaul, and the cooling and conditioning of the resonators. This time is now shorter than was needed previously, and beam time could be increased if the experimental program makes it necessary.

During 1992, 15% of the total beam time was lost due to various causes. Surprisingly the FN tandem proved less reliable that the resonators: we encountered several roll bearing failures due to misalignment, along with torn charge combs, and column resistor destruction. In this paper we would like to analyze only the difficulties encountered with the superconducting resonators and with the cryostats.

6.Vacuum accidents.

Cold cavities are very sensitive to such accidents. They were by far the most severe problems associated with our resonators.

They may happen, for example, if cracks show up in one of the ceramic-niobium brazes, when cycling in temperature the RF feed-throughs. These cracks induce pure helium leaks inside the beam vacuum from the cooling bath. Cleanliness of the R.F. surface is not degraded, but the helium pressure may locally reach the sputtering level (a few 10^{-4} mbar), preventing the resonator to operate at high field. This happened twice during the last two years and we had to remove resonators for feed-through replacement.

An other vacuum accident was due to an indium seal leak on a single cavity cryostat. Since all the cold seals (connecting cavities together or to RF ports) are of this type, it is fortunate that such leaks did not happen very often up to now.

When dismantling a resonator to repair such leaks, despite all precautions taken, chances are high to pollute the interior with dust or indium gasket fragments. Cleaning is then necessary before mounting again the resonator inside the cryostat. We try to avoid doing any chemistry which can alter the RF surface by making defects apparent which were previously hidden in the Nb material. This is particularly important for the welds (where ≈ 100 μ tungsten inclusions may be created by the TIG welding process) as our experience has shown during cavity fabrication. A simple rinsing with high purity water (10-20 MΩ.m resistivity) seems to be sufficient. Drying is done in our clean room without any heating.

Of course, after such a treatment, a strong multipactor barrier appears, but after pulsed RF conditioning the electric fields rise up again. Going back to the normal operating fields may require several days of uninterrupted RF.

Saclay Linac

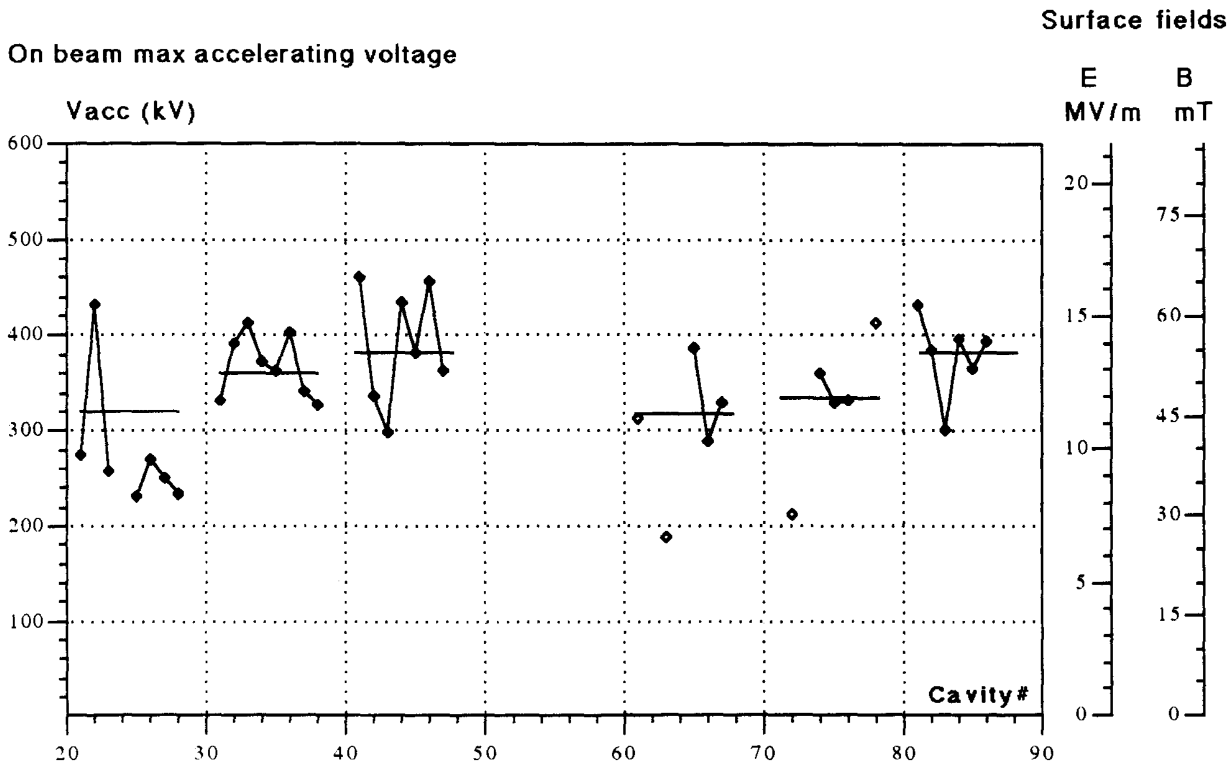

Figure 4. Running accelerating potential and maximum surface fields of the cavities. Resonator labeled "nm" means cavity m (1<= m <=8) in the nth cryostat (1<= n <=8). Data points were measured in Mai and June 1993. The horizontal lines running across the cavities of each cryostat give the average values of the potentials and fields in April 1989 during the first complete run of the machine.

A peculiar difficulty, more human than technical in nature, arise with maintaining cleanliness. Since dismantling resonators is a rather infrequent operation, and since ultimate cleanliness, like radiation, cannot be "seen" but only measured afterwards by its consequence on the R.F. properties of the cavities, the personnel in charge of these mounting operations has to be warned strongly, each time, against dust pollution, despite well publicized procedures.

7. Multipactor during operation.

Sometimes very small air leaks (observed particularly during introduction or removal of beam profile monitors) induce strong multipactor in the two rebunching resonators. These resonators are less protected from the outside than the resonators of the big accelerating cryostats for which solenoids act as efficient cryopumps. This multipactor is due mainly to frozen gases at the surface of the Niobium material as outgassing during warm-up indicates. Dust does not generates multipactor. Its disastrous effects are only seen at high field.

8. Electric fields.

We did not observe any long term degradation of the maximum electric surface field in our resonators (around 13 MV/m) since the beginning of operation of the linac (figure 4) but multipactor seems to be a more frequent problem now than it was before.

We think that maintaining the cryostats at cryogenic temperatures (4K during winter and 70K during the summer shutdown) had for consequence the build-up of frozen gas at the surface of the resonator during the last two years. We decided to heat-up the full machine to room temperature this summer to evaporate them. In this respect, one should note that the total cryogenic losses at 4K (around 270 W) did not increase much during those years, showing that the Q values of the resonators are still high.

A vacuum mass spectrometer was set recently to continuously analyze the outgassing of the most critical cryostat (second time rebuncher) during its last reheating. Interestingly enough the dominant contaminants found were only air and water vapor. Although only diffusion pumps are used on our beam lines, <u>no oil is seen in our vacuum</u>. This is because oil contamination (due mainly to the primary pump oil) is much reduced by not letting the vacuum between primary and secondary pumps to go below 4 10^{-2} mbar, using a small adjustable air leak.

9. Cryogenics

The R2TN L'Air Liquide refrigerator with two screw compressors and a Koch wet expander performs very well. We practically never need the full available power of 500 W since the total cryogenic losses of the machine are of the order of 270 W and 350 W are readily available with a single (40 g/s) compressor. Despite its good reliability, several unscheduled or accidental stops of the cryogenic installation were observed and, as a consequence, some cryostats warmed up to liquid nitrogen temperature. No serious consequences resulted for the resonators as far as electric field and multipactor are concerned.

10. Conclusion

In the early eighties, many expressed doubts about the practical application of R.F. superconductivity to real accelerators. Early failures were badly felt. Since then, considerable improvements in accelerating fields and in reliability have steadily taken place. Our experience confirms, along with that of other laboratories in U.S, Europe and Japan, that these fears were not founded. R.F. superconducting technology is becoming, more and more, the best choice for linear accelerator design.

12. References

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