# CONCLUSIONS FROM THE LISA SUPERCONDUCTING LINAC EXPERIENCE

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## Abstract

The commissioning of the experimental superconducting (SC) RF linac LISA (working at 4 K) has been completed and conclusions can be drawn regarding the performance of this low energy ( 25 MeV), high average power machine.

The illustration of the difficulties encountered in commissioning and operating this rather compact accelerator with few people can give suggestions for improvements to those interested in the application of such machines (as FEL drivers, gamma and neutron generators, etc) in a non specializaed environment.

## 1.Introduction

The INFN Frascati National Laboratories (LNF) started the LISA project, concerning the construction of an SC-RF linac in 1988, in the mainframe of an effort to promote activities in the field of SC-RF technology applied to accelerators.

At the beginning of the '90s however INFN decided the construction of the DAFNE Phi-factory to become the first priority of the Laboratories, thereby moving RF-SC activities and the LISA project to a lower priority level. The construction of the machine, started at the end of 1989, was nevertheless completed in 1993.

Lisa has been described in various conferences [1]. For ease of the reader we recall that the SC linac is composed of four independent cryostats, each housing a 4-cell 500 MHz cavity of the Desy-Hera design. We report the parameters of the machine in Table 1, where achieved and design values are shown. Question marks regard parameters that could not be measured for lack of specific instruments .

Table 1 - Parameter list of the LISA accelerator .

| | Achieved | Goal |
|---|---|---|
| Energy(MeV) | 20 | 25 |
| Bunch length(mm) | (?) | 2 |
| Peak current(A) | (?) | 5 |
| Duty cycle(%) | 2 | 2 |
| Macropulse current(mA) | 1 | 2 |
| Invariant emittance(πmrads) | 10^-5 | 10^-5 |
| Energy spread | 2x10^-3 | 2x10^-3 |
| Micropulse frequency(MHz) | 50 | 50 |
| Macropulse frequency(Hz) | 3 | 10 |

In the following two years the commissioning of LISA has been concluded with the limited forces of our small group (6 graduates and 3 technicians) and the support of external industries for maintenance and repairing of apparatus.

This has been possible thanks to the high degree of automation of the whole machine and to the easy use of the Apple MacIntosh man-machine interface. This experience should encourage those who are doubtful about installing a SC linac in University or research Lab environment that cannot afford a numerous team of specialized personnel.

On the other hand, a limited number of operators implies a careful organization of shifts in order to keep the machine running for long periods, as is necessary for an efficient use. In fact, as it takes about three days to cool-down the cavities and one day to warm-up, to which are possibly to be added a couple of days to recover the cold state in case of a transient electrical power failure, it is evident that the running period should not be less than one month. This can be achieved if an efficient automatic system of He gas recovery is provided, so that permanent presence of experienced personnel on the site is not requirted. In our case, in the absence of such a system, the compressor had to be restarted by an operator in a few tens of minutes, otherwise the gas was lost in air through the exhaust valves. This fact limited the running periods of Lisa to about two weeks, which resulted in a very lengthy and unefficient commissioning.

## 2. Commisioning of the linac

The most difficult problem we had to face during commissioning, and which ultimately limited the performance of the machine, was the presence of cavity vibrations in the cold machine, due to thermo-acoustic oscillations in the refrigerator-cryostat system. They seem to be mainly due to the close interconnection of the gas circuits of the cryostats through the common return line between valve box and refrigerator. In fact a relevant reduction of vibrations has been achieved by closing partially the gas return lines from the cryostats to the valve box, thus decoupling somehow the circuits [2]. In other similar structures ( JAERI, Japan,) where each cryostat carries on top its small refrigerator, no such vibrations have been detected. A centralized scheme like ours is therefore not to be recommended. One should at least decouple each cryostat from the system by a local phase separator.

Two of the cavities show much stronger vibrations than the others. This may be due to some internal defect of insulation between the 4 K body and the 70 k shield. When ultimately we succeeeded in limiting the vibrations of these cavities so that the corresponding frequency deviation was within the loaded bandwidth, it was evident that the voltage and phase stabilizing systems have to work at their best in order to keep the beam energy fluctuations below 1%.

The phase feedback is the more critical as it has to cope with ±45 degrees deviations. The corrections require supplementary power from the klystrons, setting a limit to the voltage obtainable from these two cavities and therefore on the maximum stable beam energy (15 MeV, well below the 20 MeV peak achieved).

All cavities show structure deformations and consequent field unflatness as deduced from the measurements of their dispersion curves [3]. The maximum deviations of the inter-cell coupling factors $K_\theta$ from their average are shown in Table 2 for the two worst Lisa cavities in comparison with a not well tuned Desy cavity of which the field unflatness has been measured. It is therefore to be expected thast in our cavities the field unflatness is of the same order (i.e.70%).

**Table II**

| | CAV-1 | CAV-4 | DESY NOT TUNED |
|---|---|---|---|
| $K_{\pi/4}$ | 1.91 % | 1.91 % | 2 % |
| $K_{\pi/2}$ | 2.32 % | 2.27 % | 2.17 % |
| $K_{3\pi/4}$ | 3.27 % | 3.16 % | 2.89 % |
| <K> | 2.5 % | 2.45 % | 2.35 % |
| ∂K/<K> | 54 % | 51 % | 38 % |
| $E_{max}/E_{min}$ | | | 1.7 |

All cavities show also Q degradation with respect to the values originally measured at the factory in horizontal tests on the cavity fully assembled in the cryostat. As shown in Fig.1, there is a decrease of the low field Q by about a factor 2, and a decrease of the field emission threshold by about 30%.

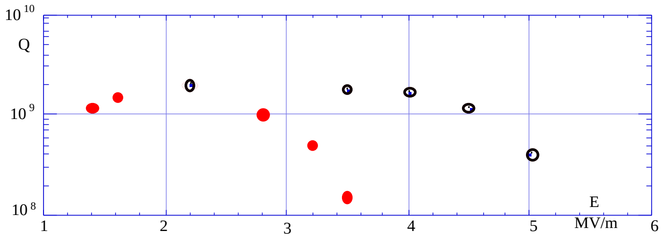

Fig.1- Typical Q vs E curve(empty dots are factory values).

This however has not been the ultimate energy limiting factor, as the pulsed regime (with several % duty cycle) is widely compatible with the cooling power of the refrigerator. Quench has rarely occurred for gradients well above 5 MV/m.

After the original degradation following the installation on the accelerator, the cavities have suffered no apparent further deterioration even though their inner walls have been hit frequently by the beam and moreover no laminar flow clean air has been employed during the frequent disassembly operations on the vacuum chamber. The machine has shown to be much sturdier in handling than feared at first.

## 3.Diagnostics issues.

Beam diagnostics have played an important role in the commissioning of the accelerator. The types of devices used are: toroids for average macropulse current, strip-lines for transverse position and beam time structure, fluorescent and OTR targets for both transverse position and shape.

Strip-lines are essential for a good beam transport through the 1 MeV arc where no fluorescent targets are available. The data acquisition system allows to display a trajectory on line (see Fig. 2), so that manual corrections can be made to minimize the distance of the trajectory from the axis. The automation of this process has not been implemented due to lack of control software manpower.

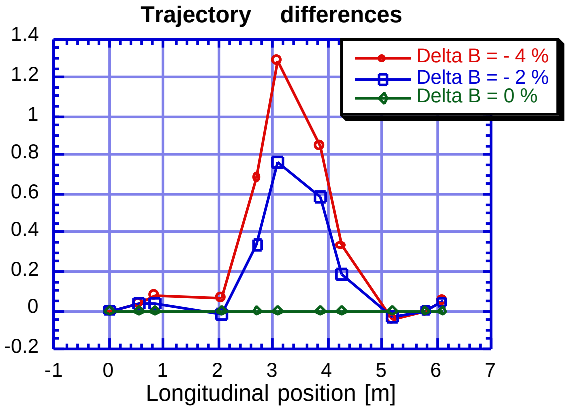

Fig. 2 - BPM measurement of the relative beam displacement in the arc varying the bending field of -2% (square points) and -4% (dot points)

The drawbacks found in the strip-lines system are scarce sensitivity, so that the readings are reliable only above 1 mA beam current, and thermal drifts that oblige to perform frequent offset calibrations. The experienced acquired in Lisa has however allowed us to design better electronics for the Desy-TTF experiment [4].

Strip-lines have also been employed in an unusual way as broadband detectors to obtain information on the time structure of the beam. The shape of the envelope of the 50 MHz lines spectrum of the signal induced by the beam on the strips gives information on the proper settings of inflector, chopper and prebuncher parameters (see Fig. 3) [5]. A proper time structure is essential for a good capture of the beam by the SC cavities.

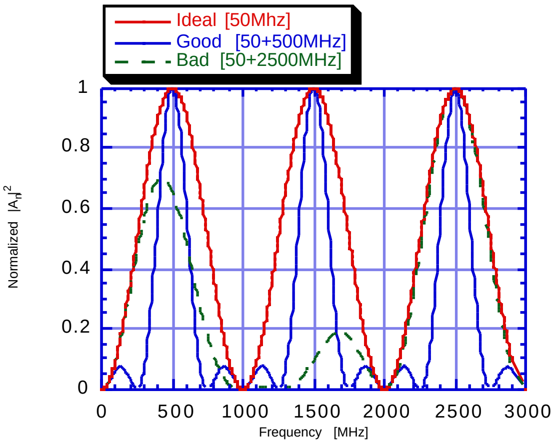

**Fig.3**- Normalized square amplitude of spectrum envelopes vs frequency. The outer full line is the ideal one(only 500 MHz buckets evenly filled), the inner full line is a good one( mainly 500 MHz buckets filled. The dashed line is a bad one, with many 2500 MHz side buckets filled.

As to fluorescent targets, in order to avoid saturation, it was found very useful to use simple oxidized Aluminium ones in the lower energy part of the injector. Optical Transition Radiation foils, originally planned only to test the prototypes for the Desy-TTF experiment, have shown to be a very effective instrument for the beam transverse charge distribution measurement at higher energies.

Measurement of bunch length, which is expected to be a few ps, was not possible because of lack of specific instruments. A tentative to use the traditional indirect method consisting in detecting energy spectrum variations vs the RF phase of one of the cavities [6] failed because the beam after the SC cavities was not stable enough over long periods. We have however prepared the hardware for a measurement on the 1 MeV injector beam, which is sufficiently stable, based on coherent transition radiation spectrum [7] and we hope to perform it in the near future.

## 4- Reliability.

A question that is often posed by potential users of SC linacs is about the reliability of operation of such a machine. Only the non traditional parts will be discussed here. It must be stated first that the operation has been too discontinuous to allow for statistics and that this machine was not intended for users. The various sectors have worked for about two months per year (in 4 shifts of two wees each) from 1992 to 1995. Only in the last two years the machine has been commissioned as a whole.

The hardware of the SC cavities has behaved well. No discarges were detected in the main couplers, due to their large oversizing, and we did not need to use the antenna cooling system. No troubles came from the HOM suppressors, which were left unterminated, due to the negligible interaction of the beam with HOMs.

The refrigeration system has performed well. We had only to substitute, after the first two years, the gas exhaust valves on the cavity LHe container, which had lost their tightness due to frequent blowing in preliminary manoeuvres. Occasional interruption of operation during the shifts was mainly caused by electrical power failure due to thunderstorms.

Another peculiar accident connected with the high charge of the beam pulse regards the glass windows through which the cameras look at the fluorescent targets. Several of these windows were broken due to charge accumulating on the surface. We solved the problem by a metalization of the surface itself.

## 5. Conclusions

Regarding general features of the accelerator, it is to be remarked that the 1 MeV injection energy is too low for a good beam capture efficiency by the SC cavities. A few more MeV would be advisable. It would also be better to place the injector on axis with the cavities, to avoid beam position fluctuations due to imperfections in the achromaticity of the arc in connection with injector beam energy variations (in our design the arc was required by the planned recirculating beam transport after the FEL interaction for energy recovering).

In conclusion, the correction of the defects of two of the cavities and some modifications of the LHe distribution system would allow LISA to attain the design goals. It is the priority given to other projects that has stopped the work on this machine. In fact many potential uses of this machine have been proposed besides the original FEL application.

The intense, high quality beam of this machine, that has allowed us to detect OTR radiation without difficulty even at 1 MeV [8], is a precious source, and many experiments have been proposed, among which the generation of high brillance monochromatic X rays through channelling in crystals, a medium intensity cold neutron source, and the test of coherent inverse Compton scattering .

## References.

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