Operating Experience with the LISA Superconducting Accelerator

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Abstract

A 1 mA beam, 1÷ 2 msec long with 1 ÷ 3 Hz repetition rate, has been successfully accelerated to 16 MeV during the last LISA cool-down. Nevertheless beam energy and position fluctuation are still a problem above 13 MeV, mainly due to insufficient phase feedback to cope with residual cavity vibrations induced by LHe bath pressure fluctuations. A spectrum of the pressure oscillations shows a peak at a frequency of 33 Hz with an amplitude of 1.5 mbar, associated with a RF phase fluctuation of the order of ±50 degrees. Cures by acting on Refrigerator parameters are illustrated and behavior of the RF properties of the cavities at high fields is discussed.

Introduction

The LISA linac consists of a normal conducting Injector followed by a Superconducting Linac. In the Injector a thermoionic Gun provides a 100 KeV beam 1 msec long with a normalized emittance $\varepsilon_n = 10^{-5}$ πmrad at 10 Hz repetition rate which is then transformed in a train of bunches of 2 mA average current with 50 MHz repetition rate by a 50+500 MHz Chopping system and a 500 MHz Pre-Buncher. Then a β-graded 2.5 GHz Capture Cavity drives the beam up to 1.1 MeV . An achromatic and isochronous arc injects the beam in the SC Linac where four 500 MHz SC accelerating cavities of the DESY-HERA type accelerate the beam up to 25 MeV with 2 10^{-3} energy spread.

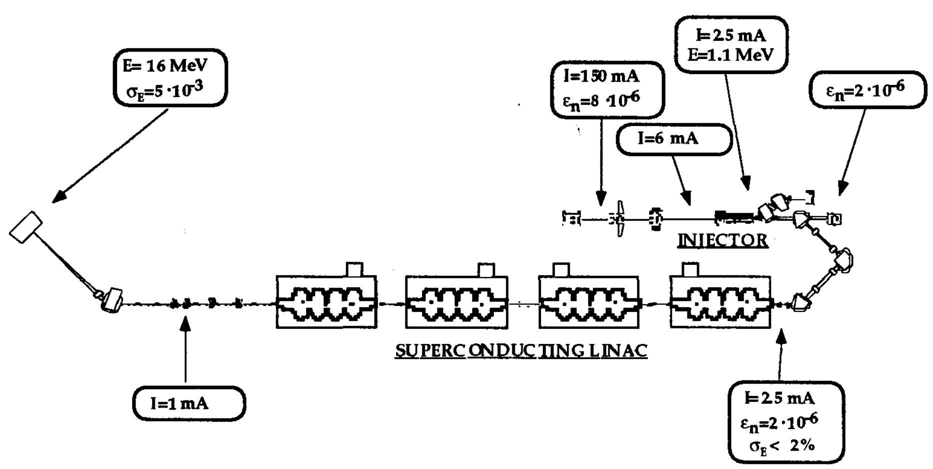

Fig. 1 - LISA layout with measured beam parameters

The choice of beam parameters was dominated by the idea of using the machine as a driver for a high power FEL in the infrared radiation region. The FEL project has been recently discarded and the LISA commissioning is now devoted to a test and training facility in the framework of the TESLA project, allowing relaxed beam parameters.

Measured beam parameters are reported in Fig. 1 showing also a general layout of the machine. One can see that the beam parameters at the entrance of the SC Linac are close to the design goals, on the contrary current, energy and energy spread are not yet optimized at the exit of the SC linac. Moreover the reproducibility of the beam is very low at higher energy (50 % of the pulses are accepted in the 2% energy window of the output spectrometer) due to a large beam energy and position fluctuations. These fluctuations are partially caused by variations of the injected beam parameters, especially the angle with respect to cavity axis, given the long distance before the next focusing quadrupole doublet. The main cause however is in the phase and amplitude fluctuation of the cavities.

Causes of beam energy and position fluctuations

A relevant problem encountered with the cold cavities was the presence of strong vibrations of intrinsic origin, i.e. not transmitted by external rotating machinery or such. The most sensitive method to detect these vibrations is to observe, with a low frequency spectrum analyzer, the output from a phase detector looking at the phase difference between the voltage incident on the cavity and that transmitted at the field pick-up.

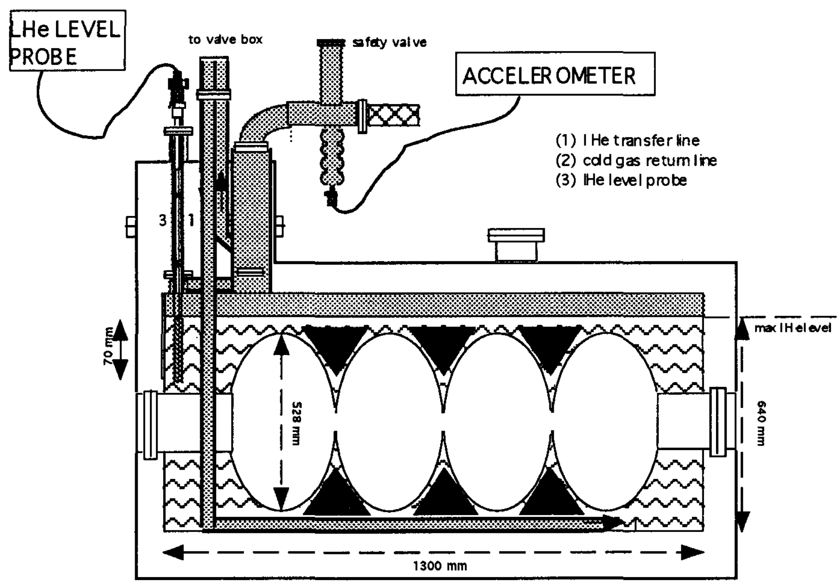

Fig. 2 - Schematic view of a LISA cryostat

A sharp correlation with the spectra of pressure oscillation in the LHe bath has been detected with an accelerometer mounted on a bellow in communication with the LHe tank, as shown in Fig. 2. A spectrum of pressure oscillation, Fig. 3, showed a peak at a frequency of 30 Hz with an amplitude of 1.5 mbar, associated with a RF phase fluctuations of the order of ± 50 degrees, the exact values being slightly dependent on the status of the refrigerator.

The voltage and phase stabilization loops have a severe task, because the amplitude of the cavity structure vibrations is such as to cause cavity eigenfrequency variations of the order of a half bandwidth (50 Hz). The amplitude loop can cope with the corresponding voltage fluctuations only up to an average cavity voltage of 3 MV, above which the klystron power saturates.

A cross spectrum between cavities shows that the frequency of the line is identical (within 1 Hz bandwidth) for all cavities, indicating that the cause of such vibrations is to be looked for in the interaction of the cryostats with the refrigerator. It could be a thermo-acoustic oscillation somewhere on the Refrigerator lines or a two-phase flow with perturbing gas bubbling. The first hypothesis is consistent with the line structure of the spectrum. The second one seems to be supported by a dependence of the phenomenon on the pressure drop between cold box and cryostats. Furthermore, it is possible that the vibration is amplified by falling into the bandwidth of a mechanical structure resonance.

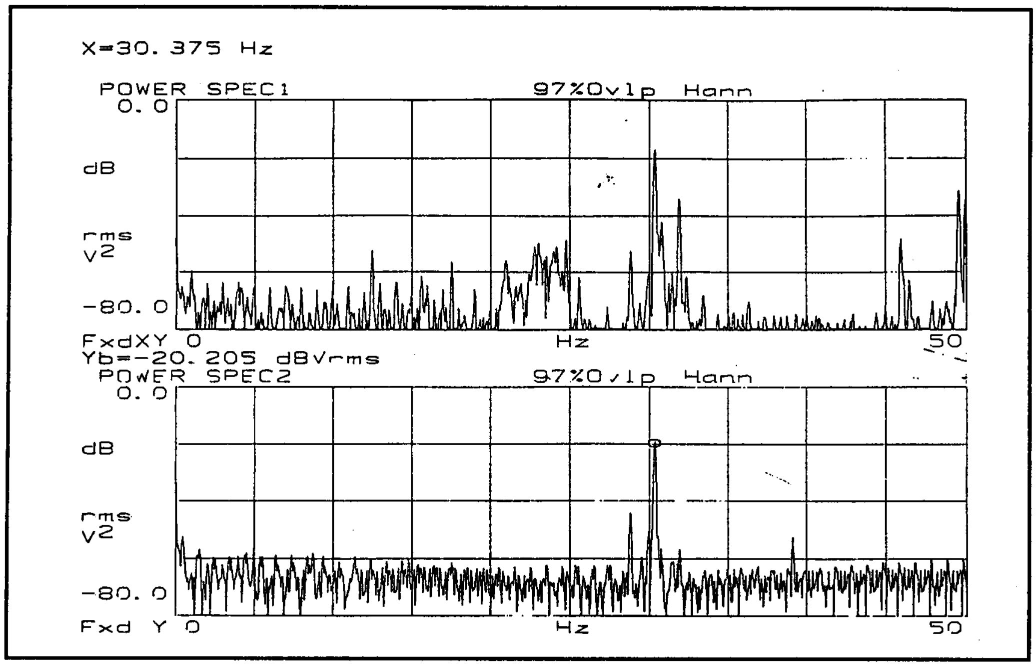

Fig. 3 - Helium pressure (above) and cavity phase error signal (below) spectra. Average bath pressure 150 mbar, it shows a peak at 30 Hz frequency with a pressure oscillation amplitude of 1.5 mbar (above) correlated to a cavity RF phase oscillation of ±50^{o} (below) at the same frequency.

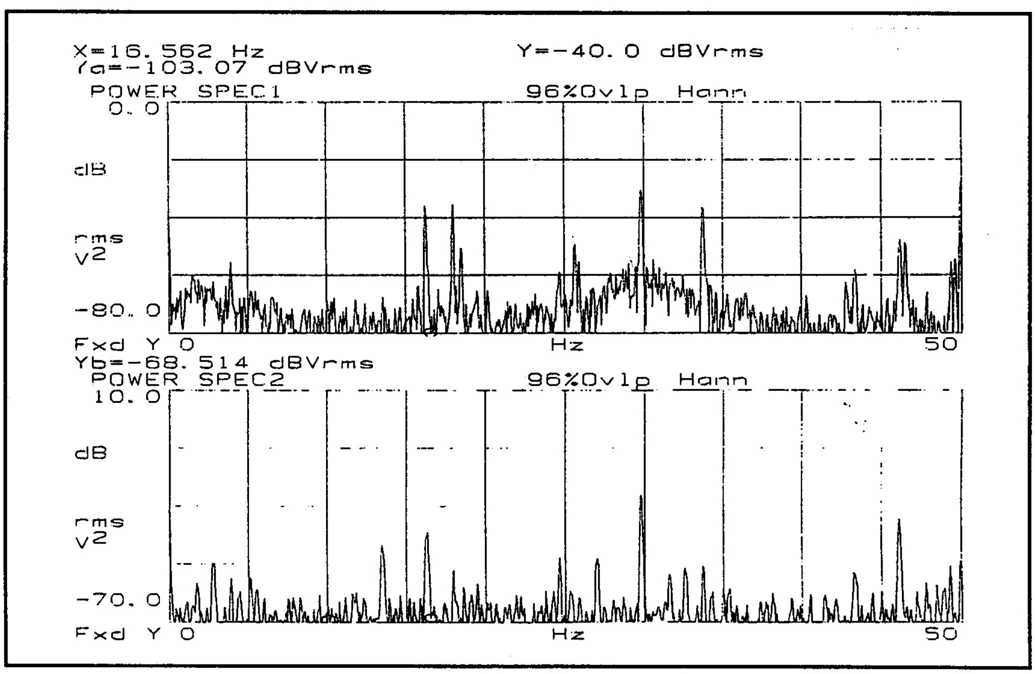

Fig. 4 - Helium pressure (above) and cavity phase error signal (below) spectra. Average bath pressure 250 mbar, it shows the same peaks as Fig. 3 at 30 Hz frequency but with a pressure oscillation amplitude of 0.2 mbar (above) correlated to a cavity phase oscillation of ±5^{o} (below)

Our attempts to reduce the beam instability has been twofold. The first way has been to modify the refrigerator parameters until we succeeded to reduce pressure oscillations and to have cavity eigenfrequency variations within the cavity bandwidth. Increasing pressure in the Suction line together with a decoupling of the Cryostats from the common gas return line allow us to work in a more stable condition up to 4 MV/m per cavity. With 250 mbar average pressure in the Cryostats, the pressure oscillation at 30 Hz frequency is reduced to 0.2 mbar amplitude correlated to a cavity phase oscillation of $\pm 5^{o}$, as shown in Fig 4.

The second task, that is still under way, is to improve the electronic feedback loops that stabilize the phase and voltage of each cavity individually

Cavities Q degradation and field unflatness.

When the cavities are operated above 4 MV/m per cavity the power dissipation exceeds the design load of the Refrigerator revealing a strong Q degradation and forcing us to work in pulsed mode. In fact Q degradation is the main limitation of cavity performance. No quench is usually detected up to 6 MV/m

A new method has been devised to measure Q_o calorimetrically, on line with the refrigerator [1]. This turns out to be important to control the performance and the stability of the machine, and can only be done calorimetrically unless the cavity is equipped with a variable coupler.

We noticed that going from factory to LISA, while at low field Qo is only slightly altered, there is a remarkable lowering of the Q versus E_{acc} curve '"knee" (from ~4 to ~3MV/m) , to be attributed to field emission as X-ray measurement also show.

This behavior could be attributed to some contaminant having migrated to the surface of the cavities from the adjacent parts of the accelerator although the vacuum level next to the cavities, obtained without taking any special precaution during assembly other than those pertaining to a good vacuum practice, is in the range of 10^{-9} mbar. We tried unsuccessfully to clean the surface by standard RF conditioning with peak accelerating fields of up to about 6 MV/m, limited by available klystron power and coupling, in short pulses (0.3 ms). The peak power turns out not to be sufficient to process cavities even after lengthy pulsing.

The low field value at which field emission becomes significant prompted us to consider possible field flatness degradation due to alteration of the tune of individual cells in the course of the various successive manipulations of the cavities. A much higher than average field in one of the cells would in fact limit the performance of the whole cavity.

Measurements of field distribution performed at the factory by the usual perturbative method had given a field unflatness figure of ±5%. Because the method could obviously not be applied to cavities in-situ, information on the order of magnitude of the field flatness could only be obtained indirectly from comparing the measured dispersion curve with the theoretical one and with similar measurements performed on known cavities, as explained in the following.

From the definition of coupling constant $K = \dfrac{\omega_\pi^2 - \omega_o^2}{2\omega_o^2}$ and dispersion relation $\omega_\vartheta^2 = \omega_o^2(1 + K(1 - \cos\vartheta))$, eliminating ω_o on the previous equations, we compute the effective coupling constants from measured resonance frequencies with the following relation: $K_\vartheta = \dfrac{\omega_\pi^2 - \omega_\vartheta^2}{2\omega_\vartheta^2 - \omega_\pi^2(1 - \cos\vartheta)}$ with $\vartheta = \dfrac{\pi}{4}, \dfrac{\pi}{2}, \dfrac{3\pi}{4}$.

In a well tuned cavity all the K_θ must be equal and hence $\Delta K/\langle K\rangle = 0$, where $\Delta K = K_\vartheta^{Max} - K_\vartheta^{min}$. On the contrary $\Delta K/\langle K\rangle \neq 0$ is an approximate indication of the cavity field unflatness.

In Table II we report coupling constants from measured frequencies of the LISA cavities and for comparison two cases of DESY cavities.

Table II

	CAV-1	CAV-2	CAV-3	CAV-4	DESY NOT TUNED	DESY WELL TUNED
$K_{\pi/4}$	1.91 %	1.87 %	1.98 %	1.91 %	2 %	2.08 %
$K_{\pi/2}$	2.32 %	1.93 %	1.83 %	2.27 %	2.17 %	2.08 %
$K_{3\pi/4}$	3.27 %	1.96 %	1.75 %	3.16 %	2.89 %	2.09 %
$<K_\theta>$	2.5 %	1.91 %	1.85 %	2.45 %	2.35 %	2.08 %
$\frac{\Delta K}{< K_\theta >}$	54 %	4.6 %	12 %	51 %	38 %	0.7 %
$\frac{E_{Max}}{E_{min}}$					1.7	1

As it is reported in pervious table Cav. 1 and Cav. 4 reveals a strong deviation from the right tune if compared to the known DESY cases. We will further investigate the field flatness measuring the voltage induced by the beam on the fundamental pass band modes which should be close to 0 except for the π mode. We will try also an optimization of the frequency working point of the machine acting on the stepping motors of the SC cavities that have tune range of around 300 KHz and looking to some improvement in the K_θ spread.

Conclusions

The designed goals of the LISA project are not far. One of the main concern i.e. pressure oscillation in the LHe tanks has been reduced to a manageable level. A deficiency of the phase feedback loops is now more evident and improvement is under way. Stability of angle and position of the injected beam are essential and an optimization of each parameters is also in course.

Acknowledgments

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References:

[1] M. Castellano, L. Catani , M. Ferrario, S. Kulinski, M. Minestrini, P. Patteri, S. Tazzari, F. Tazzioli, "On line calorimetric measurement of the quality factor of superconducting cavities", N.I.M. A332 , 347, (1993)