MICROPHONIC MEASUREMENTS ON SUPERCONDUCTING LINAC STRUCTURES [1]

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Abstract

Microphonics in multi-cell linac structures lead to energy and pointing modulation of the electron beam despite RF stabilization. Evaluation of the microphonic behavior of a 500 MHz two cell structure is planned in collaboration with Lawrence Berkeley Laboratory and Brookhaven National Laboratory. In this paper we describe a method of evaluation based on accelerometer measurements.

Introduction

Excitation of the mechanical modes of multi-cell linac structures can lead to modulation of electron beam properties[1]. Longitudinal vibrations produce energy modulation of the beam, while transverse vibrations produce both energy modulation and pointing modulation. Such behavior occurs despite RF stabilization and regardless of whether the vibrational motion produces a modulation of the structure frequency. Even at rather modest amplitudes, excitation of the mechanical modes will produce observable effects. In a nine cell 1300 MHz structure, an electron beam energy modulation greater than 1% must be expected for a 10μm amplitude longitudinal mode oscillation.

The mechanical mode spectrum of a freely suspended 1300 MHz linac structure of the CERN/DESY design has been reported previously[2]. Longitudinal and transverse modes are observed at frequencies well below 1 kHz. At room temperature in vacuum, the Q-values of these modes can exceed 6000, while at helium temperature they can be expected to rise beyond 10^6 if undamped. In the absence of vibrational isolation and mode damping, external vibrational noise sources could drive these modes to large amplitude. Despite this, little attention has been given to issues of vibration isolation and damping in the design of cryogenic systems for superconducting linac structures.

To properly address this microphonics problem, design of the cryogenic system must consider the spectra and coupling paths of all potential noise sources, the mode symmetry and spectrum of the linac structure coupled to its environment, and the mechanisms and magnitude of damping for the most important modes of motion. Although our long term objective is to provide a suitable cryogenic system design, in the near term we simply hope to evaluate, in collaboration with Lawrence Berkeley Laboratory and Brookhaven National Laboratory, the microphonic behavior of a 500 MHz two cell structure and cryogenic system built by Siemens for TRW. Our goal in this paper is to define and establish a satisfactory method of evaluation.

The ultimate means of evaluating microphonic behavior of a linac consists of beam tests. Careful measurements of beam position, pointing, energy, and timing stability provide a complete characterization. At Stanford in 1972, the energy of the 8.5 MeV superconducting injector system was shown[3] to be stable within $\pm$ 3 X 10^{-5}. Although this does not represent a complete measurement set, it places an important constraint on the magnitude of microphonics problems for the Stanford superconducting linac. For evaluating other superconducting linac systems, it would be useful to develop a method that does not require electron beam measurements. In this paper, we describe a method of evaluation that is based on accelerometer measurements at helium temperature.

Accelerometer Characteristics

Two types of accelerometers were evaluated for possible use in low temperature microphonic measurements. The first type was a commercial piezoelectric accelerometer (PCB Piezotronics 303A02) which at room temperature has a sensitivity of 10 mV/g (g = 9.8 m/s^2) or 0.4 mV/μm at 100 Hz. When cooled to 4K, these accelerometers suffer a reduction in sensitivity by factors ranging from 20 to 200 and sometimes fail due to thermal stress. Since our requirements for frequency range and frequency response flatness are minimal, we were able to switch to a much simpler and more robust disc accelerometer made from a single layer of piezo crystal attached to a thin brass plate, as used in many inexpensive audio transducers. These accelerometers have sensitivities varying from 5 to 20 mV/g at room temperature and only lose a factor of 2 in sensitivity at 4K[4], thus allowing us to measure sub-micron motion even at low frequencies and low temperatures. Because of their simple construction they are also more likely to survive thermal stress. The room temperature frequency response for a typical disc accelerometer is shown in Fig. 1.

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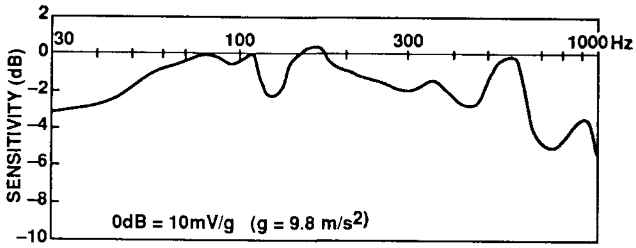

Fig. 1. Room temperature response of a typical disc accelerometer.

Measurements on a 1300 MHz structure

We have used the accelerometers described above to determine mechanical frequencies, Q-values, and RF tuning rates for the lowest mechanical modes of a freely suspended 1300 MHz two cell structure as a function of temperature. To measure mechanical modes of a free structure, the support system must not constrain the motion of interest. In our test dewar, we were forced to hang the structure vertically, and the resulting support allowed us to observe only the first longitudinal mode (L1), and only one polarization of the first and second transverse modes (T1 and T2). Horizontal support of the structure would have been preferable as it allows all longitudinal modes, and one polarization of each transverse mode.

Mechanical vibrations of the structure were driven by weakly coupling an external speaker to the support system. Modes were identified by observing the relative phase of the accelerometer signals and comparing with known modes of oscillation[2]. A spectrum analyzer was used to determine oscillation frequencies precisely. The measured frequencies of the lowest longitudinal and transverse modes at room temperature and 77K are listed in Table 1. The data indicate that the mode spectrum is shifted higher in frequency as the temperature is decreased. This can be attributed to a change in Young's modulus. Measurements of the elastic constants of niobium[5] indicate that Young's modulus increases by approximately 3% from 290K to 77K. For uniform beams, longitudinal and transverse mode frequencies are proportional to the square root of Young's modulus. The integrated thermal contraction of niobium also plays a role in increasing the mechanical frequencies, but this effect is an order of magnitude smaller than the increase in Young's modulus.

TABLE 1
Mechanical Frequencies for a Two Cell Structure at 290K and 77K

		Frequency (Hz)	
Mode Type	**Name**	**290K**	**77K**
Transverse	T1	110.2	111.6
Longitudinal	L1	273.4	276.3
Transverse	T2	374.2	375.5
Longitudinal	L2	not allowed by support	

Mechanical mode measurements on the two cell structure were extended to helium temperature with special interest in documenting the possible increase in Q with decreasing temperature and the possible damping by immersion of the structure in liquid helium. Unfortunately, the measured Q-values, which generally varied from 4000 to 6000, were limited by losses in the support system. No evidence of a temperature dependent Q-value and no evidence of damping by immersion in liquid helium was found.

Measurements were also made of the structure RF tuning rate (the modulation in accelerator mode frequency per micron of mechanical vibration amplitude) for each mechanical mode. These measurements were made at room temperature by tuning an RF oscillator to the half-power point of the accelerator mode resonance, and detecting the variations in power transmitted through the cavity which occur when the center frequency of the accelerator mode resonance shifts. The amount of power variation occurring at the mechanical mode frequency and its harmonics was observed on a spectrum analyzer. At room temperature, with an electrical Q of 10^4, we were able to detect RF frequency shifts of 100 Hz in the accelerator mode. The sensitivity of this test depends on the electrical Q of the structure and would increase at lower temperatures.

In Table 2, we list the amplitude of the RF frequency oscillation observed at the mechanical drive frequency (f_{drive}) and at its second harmonic ($2f_{drive}$) for a 1 micron amplitude of mechanical motion. Upper limits on the RF tuning rate are given for cases where the frequency shift was too small to measure. Since the experiment was conducted at room temperature, it was possible to hang the structure horizontally in both orientations allowing us to investigate all the lowest modes and polarizations. The two transverse mode polarizations had similar RF tuning rates and are presented together.

TABLE 2
RF Tuning Rates for the Lowest Frequency Mechanical Modes

Mode	**f_{drive} (Hz)**	**RF Tuning Rate**
$T1_{p1/p2}$	110.2/114.6	40 Hz/μm @ f_{drive} < 6 Hz/μm @ $2f_{drive}$
L1	273.3	2000 Hz/μm @ f_{drive} < 15 Hz/μm @ $2f_{drive}$
$T2_{p1/p2}$	370.5/374.3	180 Hz/μm @ f_{drive} < 50 Hz/μm @ $2f_{drive}$
L2	713.9	< 60 Hz/μm @ f_{drive} < 60 Hz/μm @ $2f_{drive}$

The tuning rate for the first longitudinal mode L1 is similar to the static tuning rate obtained by simply compressing the structure (1900 Hz/μm). In L1, the two cells are compressed at the same time and thus shift the structure frequency in the same direction. Since the frequency is linearly related to the length of the structure, RF frequency oscillation is expected only at the fundamental of the driving frequency. For the second longitudinal mode (L2), one cell is compressed while the other is elongated, and thus one expects the frequency shifts to cancel out. All observations on longitudinal modes are consistent with expectations. It should be noted that despite the small RF tuning rate for L2, the electron beam energy will be heavily modulated if the RF stabilization loop attempts to stabilize the fields in one of the two cells[1].

For transverse mechanical modes the situation is more complex. For these modes, one expects a very small RF tuning rate at twice the mechanical drive frequency caused by a structure length change associated with bending, but no RF tuning rate at the drive frequency itself. Contrary to expectations, the data in Table 2 shows an appreciable RF tuning rate at the drive frequency, especially for T2. This result is presumably the consequence of asymmetries in the mechanical properties of the structure and is likely characteristic of all structures. It may, however, be larger or smaller in particular structures depending on structure design and fabrication techniques.

Although the RF tuning rate data in Table 2 suggests that L1 and T2 are most likely to cause frequency modulation in the accelerator mode, experience at other labs indicates that the microphonic noise component present in the phase error of feedback loops is most likely due to T1. The expected dominance of L1 is prevented in many cases by boundary conditions which fix the length of the structure, making it impossible for L1 to exist. The dominance of T1 over T2 can be partially attributed to the fact that, for a given amount of power coupled into a mode, a lower frequency mode will have larger amplitude. Furthermore, it is likely that massive dewar components have vibrational coupling characteristics which favor transmission of low frequencies.

Conclusions

Our measurements show that many important aspects of microphonic behavior can be evaluated with simple accelerometer measurements at room temperature and helium temperature. In particular, one can determine the spectrum of frequencies at which microphonic problems may occur, as well as the likely severity of the microphonic effect at each frequency.

We have shown that the RF tuning rate for longitudinal mechanical modes is consistent with expectations. For transverse modes, however, asymmetries in the mechanical properties of the structure generate tuning rates at the mechanical drive frequency which are much larger than expected.

We will apply the microphonic evaluation techniques described here to a 500 MHz two cell structure in collaboration with Lawrence Berkeley Laboratory and Brookhaven National Laboratory.

References

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