TEMPERATURE DEPENDENT MICROPHONICS IN THE BNL ELECTRON COOLER*

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Abstract

An R&D Energy Recovery Linac (ERL), to be used in the BNL electron cooler, has been operational in a developmental setting. The ERL requires a cryogenic system to supply cooling to a superconducting RF gun and the 5-cell superconducting RF cavity system that is kept cold at 2K. The 2K superfluid bath is produced by pumping on the bath using a sub-atmospheric warm compression system. During a test run in October 2010, a resonance peak corresponding to a noise of 30 Hz was observed. This noise peak, present at all temperatures below 2K, is assumed to be of mechanical origin from the vibration of the cryopump. Another resonance noise at 16 Hz, which is characteristic of the system, was observed to shift towards the resonance at 30 Hz. The resonance noise at 16 Hz upon hitting the resonance noise at 30 Hz sets a resonance condition, thereby getting amplified by more than five times. In this paper we explore the source that causes a continuous shift in the resonance noise at 16 Hz towards the higher side until it hits the resonance noise at 30 Hz and give a physical explanation of the resonance.

INTRODUCTION

The ERL R&D program is being pursued by the Collider-Accelerator Department at BNL for a luminosity upgrade of Relativistic Heavy Ion Collider (RHIC) and for future electron-hadron/heavy ion collider, eRHIC [1]. One of its important aspects is ERL-based coherent electron cooling [2,3]. The ERL consists of a five-cell SRF accelerating cavity, named BNL1, which operates at 703.56 MHz. Figure 1 shows a schematic of the BNL1 cavity inside the helium tank, which is connected through a tube to a ballast tank at the top. The necessary cooling is provided by liquid helium through a cryogenic system that keeps the temperature below 2K. During a run in October 2010, the microphonic noise at 16 Hz was recorded and it was noticed that the frequency shifted as the level of the liquid helium (LHe) changed in the tube connecting the ballast tank to the helium tank. In this paper we investigate the shift of this microphonic noise to higher frequencies.

DESCRIPTION OF THE EXPERIMENT

We ran the BNL1 cavity with a phase lock loop (PLL) when the ballast tank was almost empty. Then the RF was turned on. The PLL locks the RF to the cavity resonant frequency based on the difference between the phases of the driving signal and the pick-up probe. The PLL error was measured by a 16-bit ADC with a sample rate of 16384 Hz. Since the PLL follows the cavity resonant frequency, an FTT of the PLL error gives a spectrum of the microphonics in the cavity.

Each FTT was done on one-seconds worth of data and was repeated every second so the resulting spectra do not overlap in the time domain. Each frequency bin therefore has a resolution of one Hz.

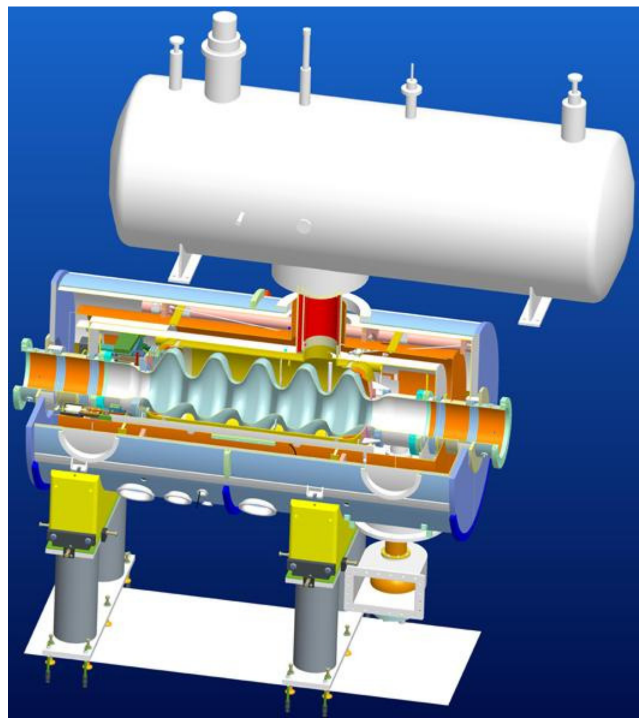

Figure 1: Schematic of BNL1 cavities immersed in helium tank (below) and connected to the ballast tank (above).

DATA ANALYSIS

Observation of the shift in microphonics

The microphonic noise present at 30 Hz, originates from the mechanical vibration of the liquid ring pump, was present at all temperatures. The RF was turned on when the ballast tank was almost empty as indicated by the probe marking the level of LHe in it. At the same time the liquid ring pump (cryopump) was turned on to cool down the cavity by sucking out the helium vapour causing boiling of the LHe. The microphonic noise peaking at 16 Hz, was found to shift towards higher frequencies only during the time when the level of LHe varied from top to bottom in the tube connecting the ballast bank to the helium tank. In Figure 2, it is shown that when the

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resonance noise at 16 Hz hits the 30 Hz driving frequency of the liquid ring pump, a resonance is excited and the amplitude of the microphonics gets amplified by more than five times.

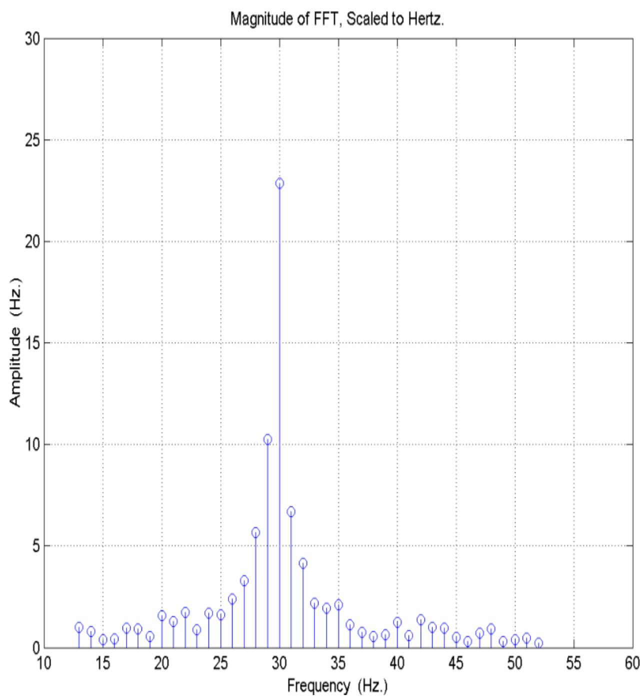

Figure 2: Onset of resonance near the 30 Hz line.

The cavity temperature varied from 1.98K to 1.88K during the time when the phenomenon of shift in microphonics occurs.

Origin of the drifting microphonics

We propose that an mth-mode resonance column, similar to a pipe organ closed at both ends, is set up in the tube filled with LHe. As the LHe boils off, the resonance column decreases in the tube. Accordingly, the resonance condition changes and so does the resonant frequency. When the tube is completely devoid of the LHe, the resonance column vanishes and hence no further drift in frequency occurs.

This mth-mode resonance column is formed by the speed of second sound in LHe when the tube is partially or fully filled with LHe. The speed of these entropy waves is temperature dependent. Figure 3 shows a polynomial fit based on the published data to get a temperature dependence of the speed of the second sound in LHe [4].

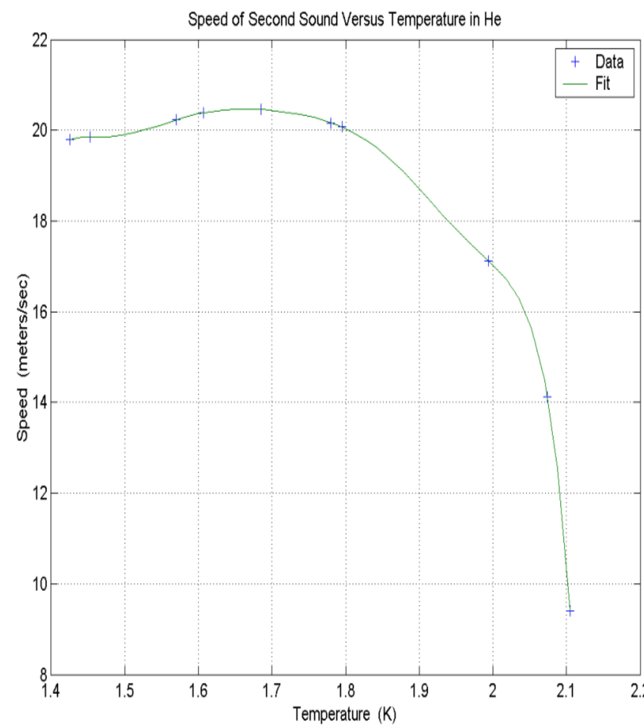

Figure 3: Temperature dependence of speed of second sound in liquid helium [4].

Analysis of the resonating column

Let the initial length of the tube be denoted by L_0, its cross sectional area by A, and the boil-off rate of LHe by $r_B(t)$. The effective length of the resonance column, denoted by $L(t)$, can then be expressed by

$$L(t) = L_0 - \frac{r_B(t)t}{\rho_{LHe}\, A}. \qquad (1)$$

The cross-sectional diameter of the tube is 6.06 inches and the density of LHe at temperatures below 2K is 0.146 gm/cm^3. Expressing $L(t)$ as an mth-mode resonance column, the initial length L_0 can be rewritten as

$$L_0 = \frac{m}{2}\frac{v_{LHe}(t)}{f(t)} + \Delta\tau\left(\sum_{\tau=0}^{t} R(\tau)\right), \qquad (2)$$

where

$$\frac{r_B(t)}{\rho_{LHe}\, A} = R(t). \qquad (3)$$

The cryogenic sample rate, denoted by Δτ, was set 15 seconds during the experiments. We took the discrete data values of all the time dependent quantities in eq. (2) and plotted for a constant L_0. Figure 4 shows a plot of boil-off rate, noise frequency, L_0, cavity temperature and helium pressure as a function of time.

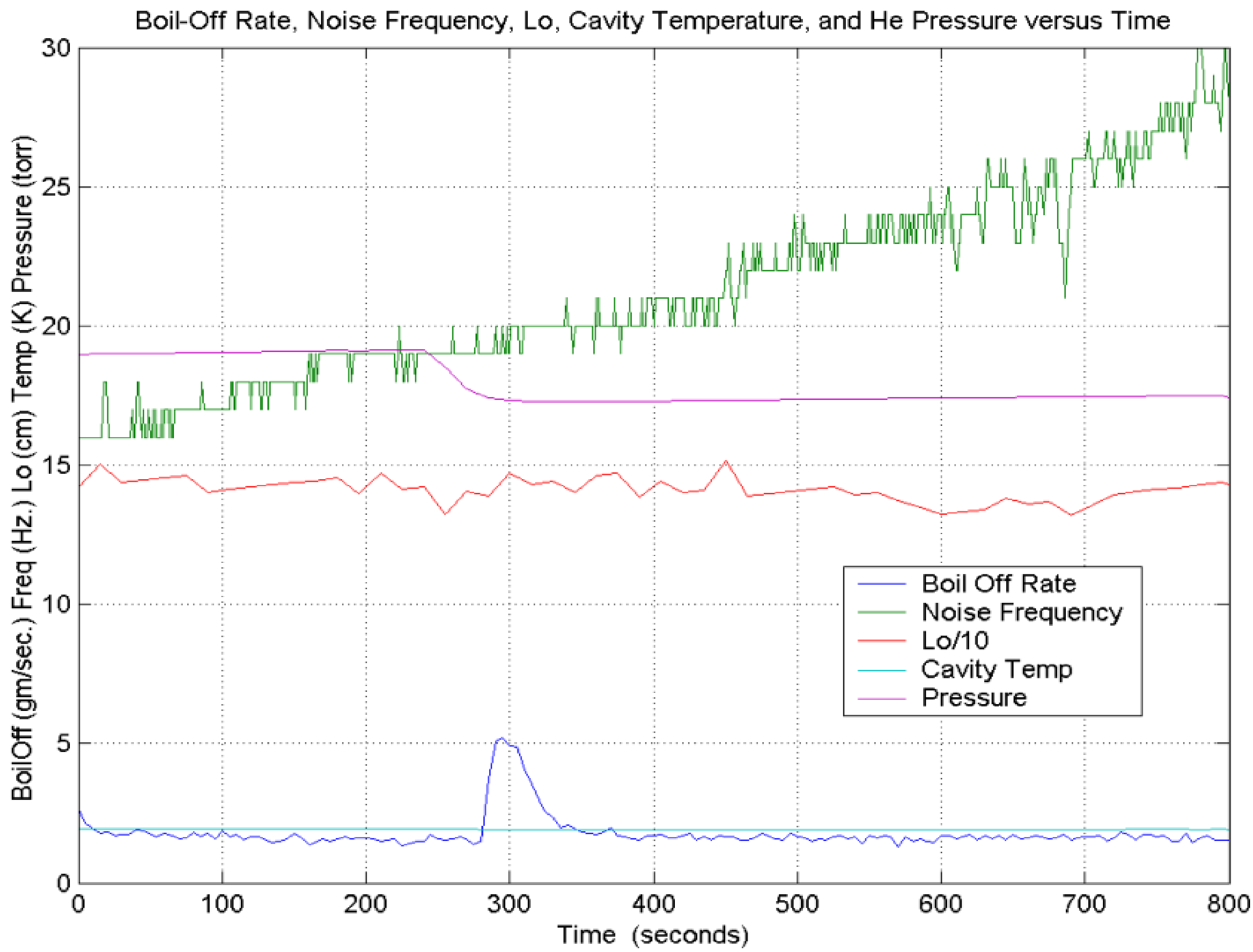

Figure 4: Change in boil-off rate, noise frequency, L_0, cavity temperature and helium pressure as a function of time.

We found that a choice of m = 3, i.e., the third harmonic gives a constant L_0 = 140 cm. By looking at the drawings, it is found that the effective length of the tube starting from the bottom of the ballast tank to the surface of the cavity is approximately equal to L_0.

CONCLUSION

The microphonic noise present at 16 Hz is a result of a resonance being excited by an unknown source, possibly by the blower of the cryogenic system. This resonance frequency shifts towards higher frequencies as the level of LHe decreases in the connecting tube. When the tube was empty, we further reduced the temperature of the cavity by lowering the pressure inside the helium tank, no further drift in the frequency was found. This suggests that it is not a temperature dependent phenomenon.

REFERENCES

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