

# An Ultrasonic-Based Calorimetric Sensor for Assessment of AC Losses in HTS Power Devices

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## Motivation

The measurement of the excess evaporation of the liquid nitrogen can provide a calorimetric method to assess HTS losses. A big advantage of such a method over the electromagnetic methods is the independence of the existing harmonics. A simple and low-cost ultrasonic sensor along with an Arduino microcontroller is exploited to sense the LN<sub>2</sub> surface level of a cryostat and hence the energy losses from the HTS.

## Experimental tests

The prototype of the Data Acquisition System relies on an ultrasound sensor with an Arduino Uno. A linear diode temperature sensor was placed at the approximate level of the sensor to read its temperature. Such assembly was tested while facing the liquid nitrogen surface having a scale for gravimetric measures as reference.

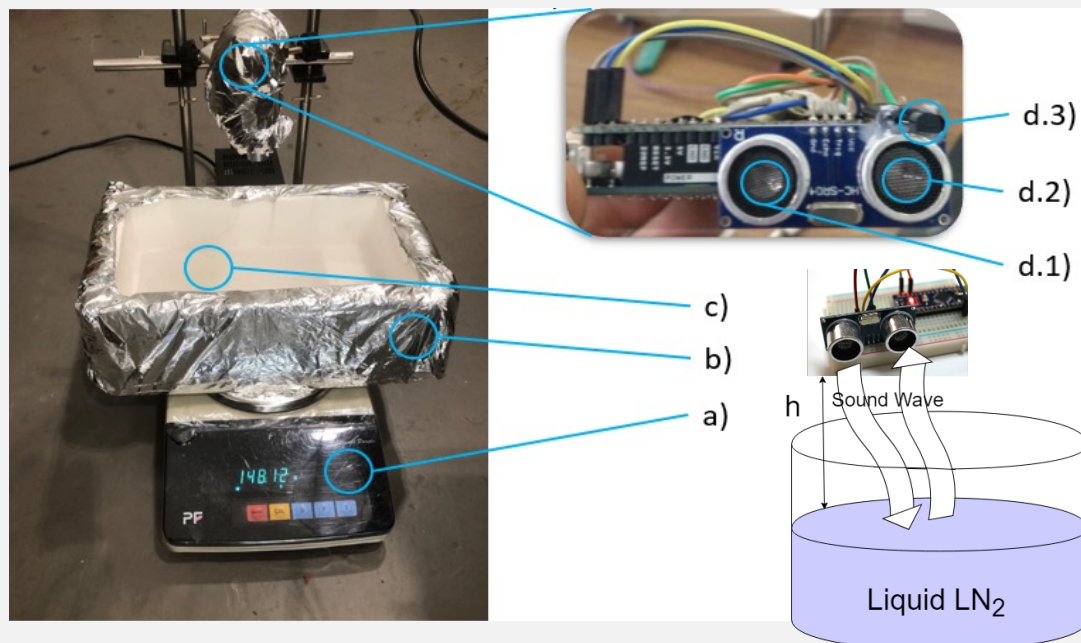


Figure 1 — a) Balance, b) LN<sub>2</sub>, c) MLI, d) cryostat, d.1) Ultrasound emitter, d.2) Ultrasound receiver, d.3) Linearized integrated diode thermometer.

## Data and Discussion

The first test was performed on an open container (as represented in fig.1), in which by observing the clusters of blue data points, and the reference curve, one finds the same slope along the mid clusters, sometimes affected by either a positive or a negative offset. It suggests that the translocation of the vapours formed above the LN<sub>2</sub> surface provokes a reflection of the sound wave being misread as a rise of the surface level (observed e.g., in the samples from 250 seconds to 350 seconds). When this vapours cloud rise too close to the ultrasound sensor, the correct measure for distance fails, and provides outlier data points such as observed in the samples retrieved around the 400 seconds' mark. With such a vapour cloud, the assumption of a linear temperature gradient along the air column also fails.

The second test was performed on a closed container, featuring no interaction with convection air currents and a restricted access of vapours to form the cloud over the LN<sub>2</sub> surface. Blue data points were read, against the same weighing reference. This run points to a severe height offset in the measured surface levels and a same order of magnitude slope that can be easily calibrated.

Overall, the experimental tests provide strong evidence that the system can work, but in order to do so, the conditions in which it is used must be further controlled.

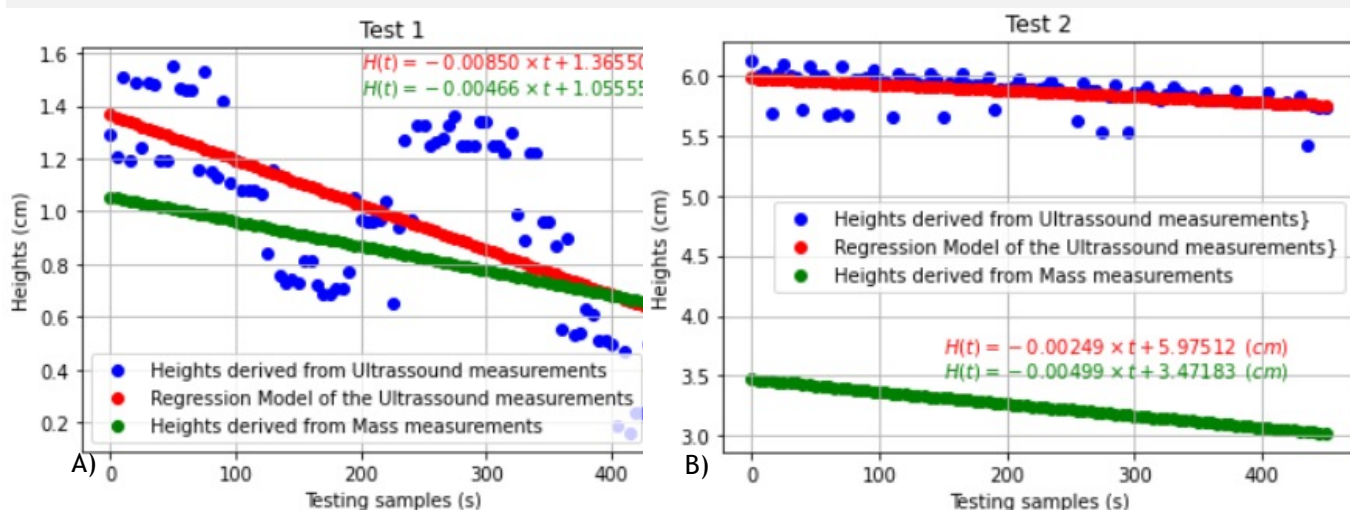


Figure 4 – A) first test, open container; B) second test, closed container.

## Acknowledgements

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## References

[1] <https://webbook.nist.gov/>

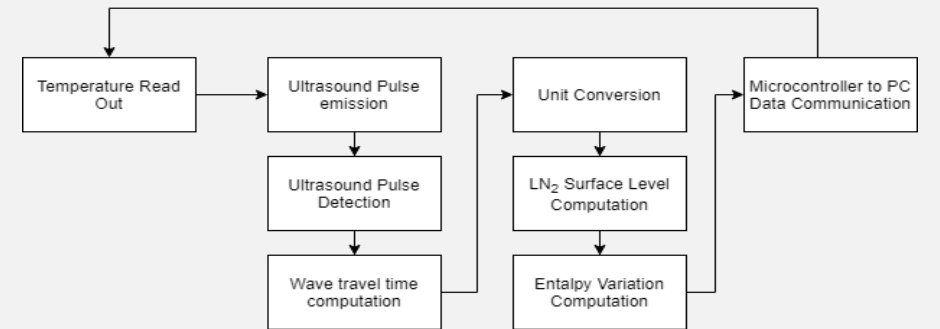


Figure 2 – Simplified high-level flowchart of the operation of the Arduino based Cryostat.

## Methods

A linear temperature profile was assumed for the vertical air column ( $h$ ) between the sensor and the liquid surface (at a constant 77 K), while the dependence of the speed of sound for vapor nitrogen was assumed under NIST data [1] as:  $v \cong 20\sqrt{T}$  (SI) (fig.3). The liquid height is deduced as:

$$L = L_0 - 5t \times \left( \frac{T-77}{\sqrt{T}-\sqrt{77}} \right) \text{ (SI)(m)} \quad (1)$$

$L$ : LN<sub>2</sub> height

$L_0$ : distance from sensor to bottom of container

$T$ : sensor temperature

$t$ : travel time (receiver to emitter, for travelling  $2h$ )

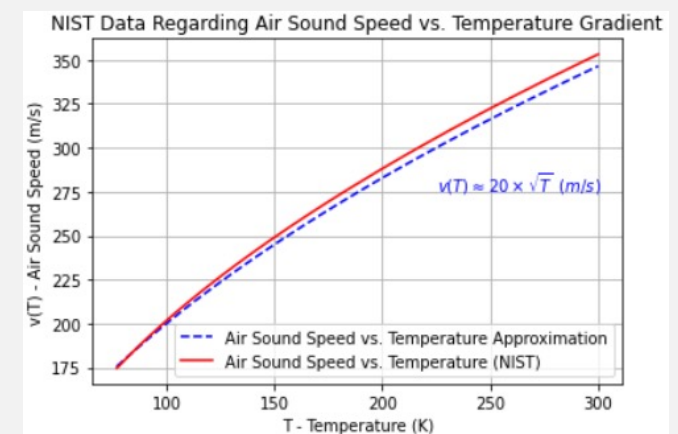


Figure 3 – Air sound velocity (red) temperature and its linear approximation model (blue).

From the *real time* measurement of liquid nitrogen level, a time rate of heat losses ( $\dot{Q}$ ) is monitored:

$$\dot{Q} = A l \rho \dot{L} \text{ (SI) (W)} \quad (2)$$

$$\dot{L}(t) = L(t_n) - L(t_n - t_{n-1}) \text{ (SI) (m)} \quad (3)$$

$$L_{ref}(t) = m(t_n) \times (\rho A)^{-1} \text{ (SI) (m)} \quad (4)$$

$\dot{Q}$ : dissipated power

$A$ : surface area of the LN<sub>2</sub> container

$l$ : latent heat of vaporization for LN<sub>2</sub>

$L(t)$ : t-sample of the surface level of LN<sub>2</sub>

$m(t)$ : t-sample of the rate of mass of LN<sub>2</sub>, taken as a reference

$\dot{L}$ : Surface level rate samples of LN<sub>2</sub>

$\rho$ : Volumetric mass of LN<sub>2</sub>

## Challenges and Conclusions

- Most of the challenges are referred to the fact that the convection currents are affecting both the vapor cloud and the temperature gradient.
- The solid angle of sensing seems to be large enough to read the walls of the container yielding wrong data, while the vapor cloud may be reflecting the signal on its level of highest density, whilst there is a minimum liquid height needed to ensure that the read reflection happens at the liquid-vapor interface.
- Furthermore, the cooling of the sensor, affected by the vapors, may lead to uneven thermal contractions of its board, changing the direction of the performed measurement.
- Finally, in optimal conditions the  $T$  gradient may also not be as linear as assumed.
- The system seems promising although further control, calibration and assessment of the temperature profile are needed in order to turn the presented breadboard system into a more enabling and viable one for HTS losses assessment.