

Performance assessment of ultrasonic waves for bubble control in LOX tanks

F. Suñol¹, D. A. Ochoa², M. Granados³, J. E. García⁴, and R. González-Cinca⁵

Department of Physics, UPC-BarcelonaTech, Barcelona, Spain;

¹francesc.sunol@upc.edu, ²diego.a.ochoa@upc.edu, ³marta.granados.jimenez@estudiant.upc.edu, ⁴jose.eduardo.garcia@upc.edu, ⁵ricard.gonzalez@upc.edu

Introduction

An efficient long-term storage of cryogenic propellants is a challenge for future space exploration missions. In long duration missions in low Earth orbit, issues associated to long-term storage, such as the cryogenic propellant loss due to boil-off, will require a proper management (Salerno 1999, Motil 2007). The vapour bubbles formed as a result of boil-off can generate foam structures, which could be hazardous in different operations in orbit. Since current heat insulation technologies are not able to provide a sufficient control of boil-off for long times, other techniques are required to minimize the effects of boiling in fuel tanks. An approach recently proposed by the UPC Laboratory of Microgravity consists in the use of acoustic fields for the control and elimination of bubbles. Bubble dynamics can be managed by the application of an acoustic field (Leighton 1974, Crum 1975). In the proposed technique, the force due to the acoustic wave generated by a piezoelectric transducer detaches the bubbles from the tank walls and moves them to the subcooled liquid where they collapse. This technique is currently under study in microgravity conditions at non-cryogenic temperatures. To be applicable in space, the technology has to be validated at cryogenic temperatures. However, numerous attempts to generate a valid acoustic signal at low temperatures have been performed without success. This is due to two facts: on one hand, piezoelectric materials are known to work lousy at the desired cryogenic conditions; on the other hand, the acoustic matching layer material loses its transmission properties at low temperatures, and consequently no acoustic signals can be transmitted into the fuel tank. However, recent studies have shown that epoxy resin-based acoustic matching layers can exhibit an increase in the transmission coefficient at cryogenic conditions, and experimental results show that the amplitude of the transmitted signal at low temperatures can increase by a factor of 1.5 the amplitude obtained at room temperature.

Experimental Setup

A transducer-rod system was built to test the possibility of using piezoelectric ceramics to generate ultrasonic pulses at cryogenic temperatures. This system consists in an aluminum rod 75 mm long and with a 12 mm x 12 mm square section. The shape of the rod ensures that one face of the rod is always in thermal contact with the platform connected to the cold finger, ensuring an optimal heat transfer from the cold finger of the cryogenic system to the transducer-rod system. Two lead zirconate titanate (PZT) based piezoelectric ceramics were attached mechanically at each end of the rod. The disc-

shaped (1 mm thickness and 10 mm diameter) piezoelectric ceramics act as transducers that convert an electrical signal to an acoustic signal and vice-versa. One transducer acts as an emitter while the other one acts as a receiver. With the aim to ensure an optimal acoustic energy transfer to the aluminum rod, different materials were tested as acoustic matching layer. The best results were obtained using an epoxy resin, that increase linearly the acoustic impedance with a decrease of temperature.

Experimental measurements were obtained in a closed-loop cryogenic system. Liquid helium was recirculated through a cold finger using an ARS-4HW compressor and refrigerated by a Polyscience 6000 chiller. The transducer-rod system was placed inside a custom high-vacuum chamber with cylindrical shape, with a height of 20 cm and a diameter of 25 cm, built by Arscryo. Through thermal contact, the cold-finger is able to cool the cryogenic chamber to temperatures around 20 K. Temperature was reduced from 300 K to 87 K, while the pressure in the chamber ranged from 10^{-5} mbar to 10^{-7} mbar. Rectangular pulses with an amplitude of $V_{pp} = 20$ V and a width of 250 ns were generated at a frequency of 1 KHz using an Agilent 33220A generator, and sent to the emitter transducer. The electric pulse was converted to an acoustic signal that travels through the aluminum rod, and then converted back to an electric signal by the receiver transducer. The electric signal at the receiver was captured using an oscilloscope Keysight DSOX2004A. In order to reduce the inherent noise, the signal was averaged over 2048 samples.

Results and discussion

With the aim to study the feasibility of generating an ultrasonic signal at cryogenic conditions, a rectangular pulse is sent to the emitter transducer and converted to an acoustic signal. Part of the energy of the acoustic signal is reflected inside the piezoelectric ceramics and another part is transmitted into the aluminum rod. The acoustic matching layer determines the amount of energy transmitted into the rod. Previous measurements using cyanocrilate as acoustic matching layer showed that the amplitude of the received signal drops as the temperature approaches 130 K. Numerous attempts to generate an ultrasonic signal below 130 K were unsuccessful. However, using an epoxy resin-based matching layer, an ultrasonic signal with an increasing amplitude as the temperature decreases was obtained.

The transmitted acoustic signal travels at the speed of sound through the aluminum rod and after 12 μ s, the signal is received in the receiver transducer and converted back to an electric signal. Fig. 1 shows an example of the shape of the received signal at different temperatures. 1. The peak-to-peak

amplitude of the received voltage increases as the temperature decreases.

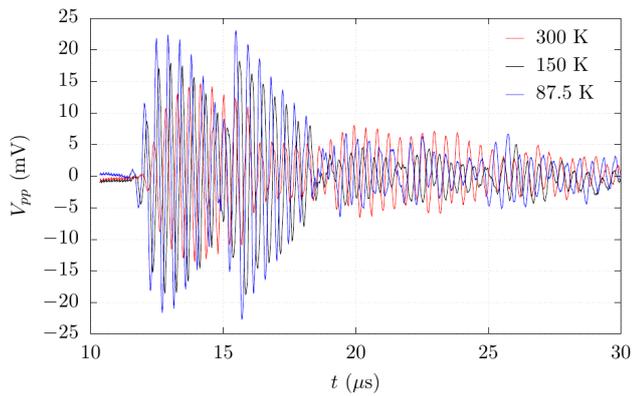


Figure 1: Shape of the received acoustic signal at different temperatures.

The peak-to-peak amplitude of the received signal was measured at different temperatures, from room temperature (300 K) to a temperature slightly below the boiling point of liquid oxygen (Fig.2). The peak-to-peak amplitude increases as temperature decreases, up to a factor of 1.5 compared with the one obtained at room temperature. This is due to an increase in the acoustic factor of 1.5 compared to the one obtained at room temperature, which is associated to an increase in the acoustic impedance of the epoxy-resin material as the temperature drops.

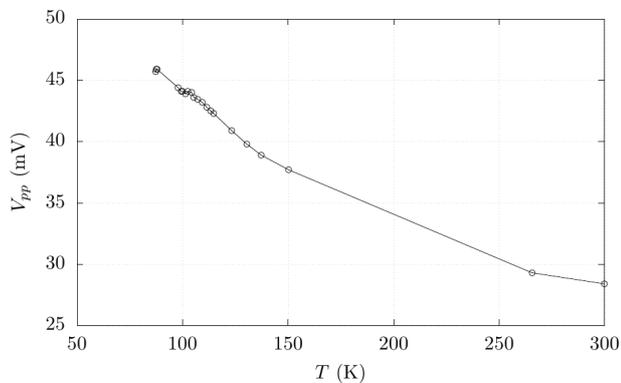


Figure 2: Peak-to-peak amplitude of the received acoustic signal as a function of the temperature.

Conclusions

Experimental measurements have been performed at cryogenic conditions to study the feasibility of generating ultrasonic signals at low temperatures. Experiments revealed that epoxy resin-based acoustic matching layers can exhibit an increase in the transmission coefficient at cryogenic conditions. The results obtained show that the amplitude of the transmitted signal at cryogenic temperatures can increase by a factor of 1.5 the value obtained at room temperature.

Acknowledgements

This research was supported by the Spanish Agencia Estatal de Investigación (project ESP2015-72277-EXP).

References

- L.A. Crum, Bjerknes forces on bubbles in a stationary sound field, *J. Acoust. Soc. Am.* 57, 1363 (1975).
- T.G. Leighton, *The Acoustic Bubble*, Academic Press, New York (1974).
- S. M. Motil, M. L. Meyer, and S. P. Tucker, *Cryogenic fluid management technologies for advanced green propulsion systems*, Technical Report TM-2007-214810, NASA (2007).
- L. J. Salerno and P. Kittel, *Cryogenics and the human exploration of Mars*, *Cryogenics*, 39:381-388, (1999).