Introduction

Particle accelerators are best known as facilities devoted to experiments at the energy or intensity frontier of subatomic physics. However, they also find application in medicine, the food industry, and materials science. In medicine they are used for cancer therapy, and the production of therapeutic and diagnostic isotopes; in food science they are used for sterilization; and in materials science they see a multitude of uses from low energy ion-implantation to high brilliance light sources. Canadian physicists are participating in two accelerator projects at the opposite ends of the energy spectrum. Following on from the Large Hadron Collider at CERN in Geneva, the high energy physics community has agreed that the next global research facility in the field should be the International Linear Collider; a 30 km long, 500 GeV machine designed to study the Higgs boson in electron-positron collisions. At the opposite end of the energy scale, the TRIUMF ARIEL machine is a 50 MeV electron linear accelerator. TRIUMF is the world leader in experimentation on exotic nuclei and stellar processes with accelerated radioactive beams. The design of this machine uses five of the same SRF accelerating cavities as are used in the ILC. The cavities for the TRIUMF machine could be obtained from abroad. However, given our aim of participating in the ILC, and given the impact SRF technology will have on areas beyond subatomic physics, there is an opportunity to develop expertise in this technology in Canada. In the process we aim to transfer the technology to Canadian industry, and have a qualified producer of ILC cavities in Canada. TRIUMF has already developed significant superconducting expertise in Canadian industry, with the production of cavities for the ISAC-II accelerator, but much remains to be done in achieving success with the more challenging cavities need for the eLINAC and the ILC.

Overview and Scientific Aims of the Project.

The production of the large number of SRF cavities required for the ILC will be a prodigious industrial undertaking. Cavity production will certainly not all be done by a single manufacturer. At present only a handful of companies in the US, Europe and Asia are certified as potential production sites. The TRIUMF laboratory is already working with PAVAC Industries Inc., of Richmond B.C. with a view to this company becoming a supplier of cavities for the ILC. PAVAC produced SRF cavities for the ISAC machine at TRIUMF, and has already produced 1.3GHz cavities for tests at TRIUMF.

In order to determine whether a particular cavity design and surface preparation will perform, it must be tested at the design accelerating electric field. The cavity is inserted into a cryostat and immersed in liquid helium at 4K. The cryostat is then pumped to lower the pressure thus lowering the temperature of the liquid helium, and cavity, to an operating point of 1.9 K. The accelerating electric field is built up by injecting radio frequency power at the cavity resonant frequency. The electric field sustained in the cavity can be determined by measuring the transmitted and reflected RF power, and the characteristic time for energy stored in the cavity to dissipate. As the RF power in a cavity is increased the accelerating electric field in the cavity increases, and so also does the magnetic field in the cavity. In fact, the ultimate limitation on the accelerating field of a cavity design is at what point the surface magnetic field at some point in the cavity exceeds the critical magnetic field for niobium. This is rarely the limiting factor for practical cavities. The electric field in the cavity is usually limited by one of various possible sources of energy loss. The sources of energy loss are characterized by the Q-value. This is related to the sharpness of the resonance of the cavity, just as in any other resonant circuit.

The Q-value in practical cavities is often limited by the energy absorbed by electrons emitted from the inner surface of the cavity. This can be a resonant process (multipacting) or, at higher electric fields, non-resonant emission of electrons from the surface under the influence of the intense electric field. Field emission can lower the Q-value just by absorbing RF energy, or the field emitted electrons can be accelerated in the electric field and cause a quench where they strike the inner surface of the cavity. Field emission is enhanced by any surface defects on the inner surface of the cavity, such as poor welds, defects in the material, dust particles, or even bacteria which have grown on, or been deposited on, the surface after the high pressure rinse.

Temperature Mapping:

Without some local diagnostics, a cryogenic RF test just tells one whether the cavity gradient was limited by multipacting, a quench, or field emission. If the cavity quenches at the maximum theoretical field there is little to understand. However if it is limited below the theoretical maximum, it is important to have some system which shows where the problem is. If a cavity does not reach the theoretical maximum gradient, this is usually due to multipacting or field emission. Multipacting is the emission of electrons, usually from surface contamination or defects in the niobium surface, in orbits which are resonant with the electric and magnetic fields in the cavity; field emission is similar, but is a non-resonant process. Either of these effects will absorb the input RF power and limit the attainable Q-value and maximum accelerating gradient, and lead to local heating of

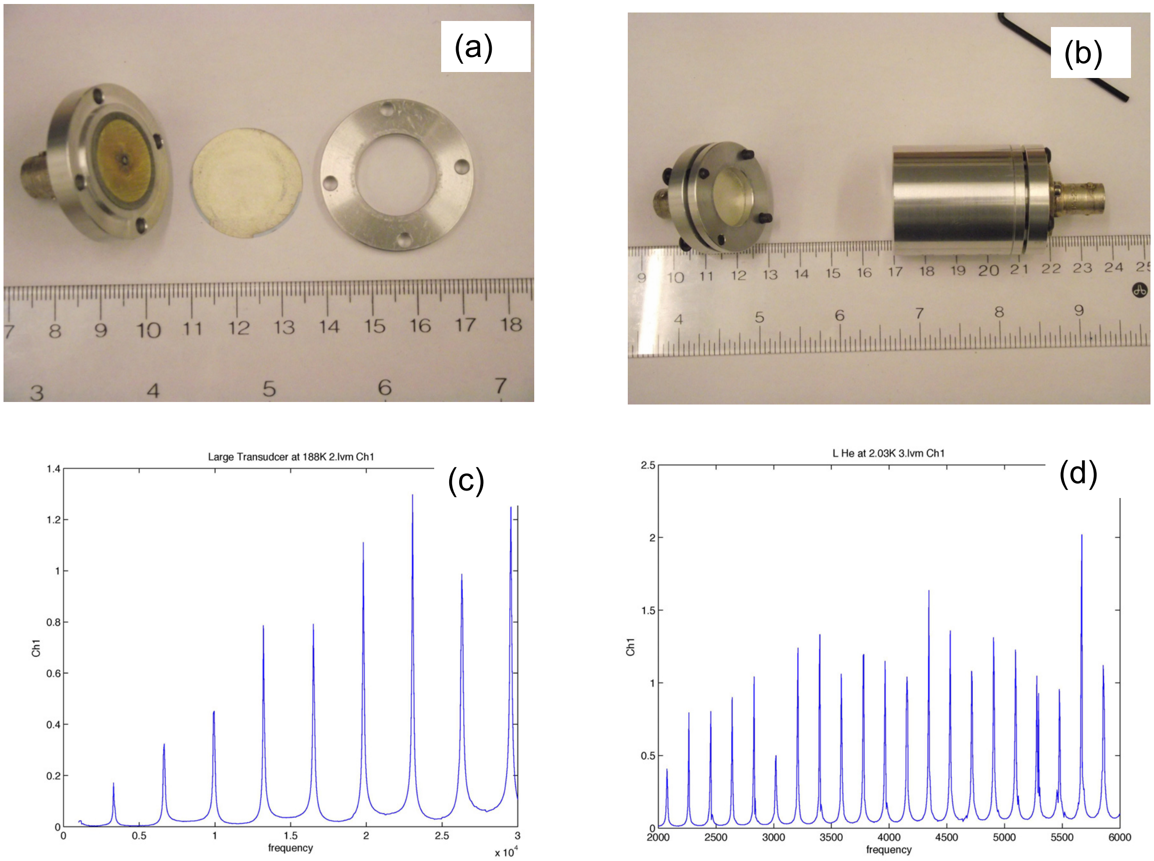

Figure 1: Second sound sensors for triangulation of quench position. A dismantled transducer, with membrane, is shown in (a), two transducers being assembled onto a pipe resonator are shown in (b). Resonances for normal sound are shown for gaseous nitrogen at 188K in (c), and second sound resonances in liquid helium at 2.03K are shown in (d). Note the very different frequency scales in (c) and (d) corresponding to the order of magnitude difference in the propagation velocity of normal sound, and second sound.

the cavity. Mapping this local heating is an excellent diagnostic of any flaws in the cavity surface. Mapping systems using high accuracy carbon resistors have been used at various institutions to temperature map the surface of multi-cell cavities. These systems are complex and expensive, and have a rather slow response time. A much more efficient approach to multi-cell cavity testing is to locate the single cell which has the problem, and then apply an accurate temperature mapping system to that cell alone.

As suggested by several workers, and most recently Z. Conway of Cornell, heat waves propagating in the liquid helium below the lambda point can be received by an array of sensors, and triangulation used to identify the source. To be more correct, these heat waves are in fact enthalpy waves. In the two fluid model of superfluid liquid helium these enthalpy waves correspond to waves of variation in the local relative concentration of the super and normal fluids. These enthalpy waves can be detected, and produced, by OST transducers. These are metalized porous membranes, the pore size being typically 0.2

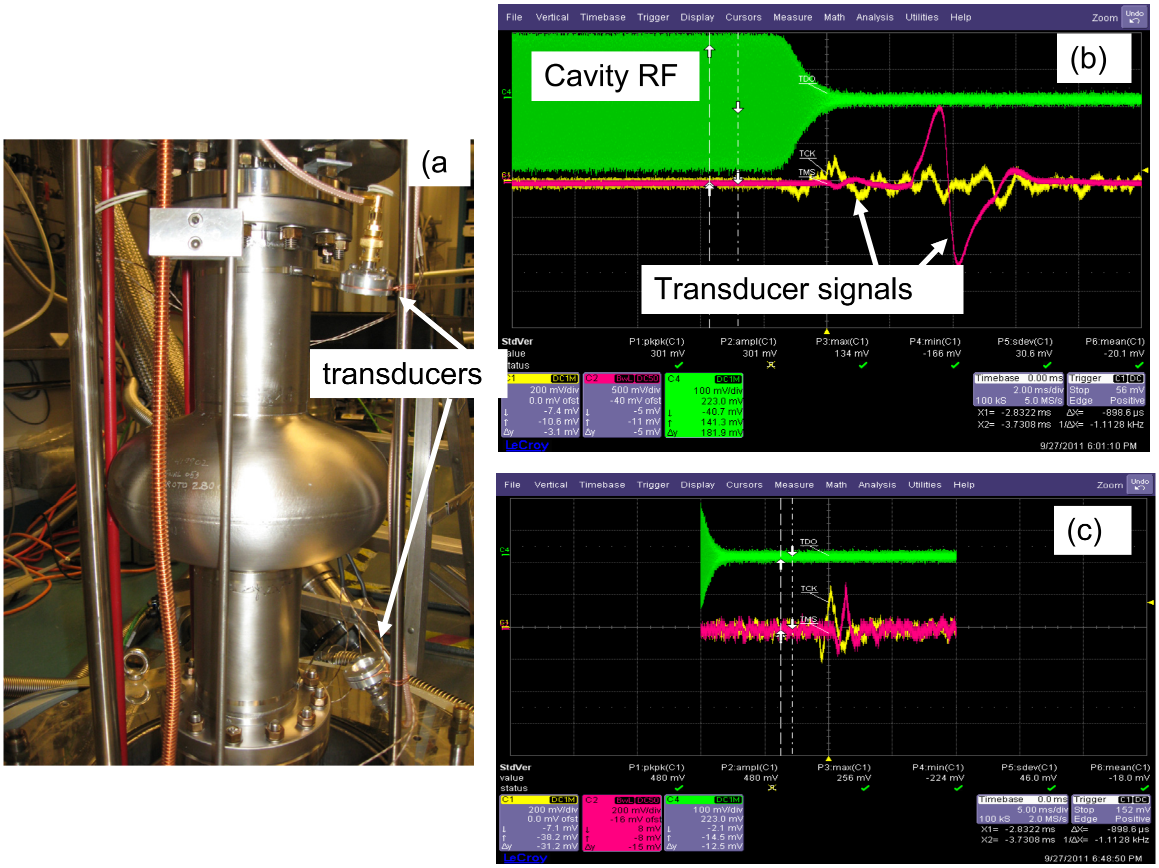

Figure 2: First observation at TRIUMF of second sound from cavity quench. In (a) the two transducers can be seen pointed at the upper and lower hemispheres of the cavity under test. In (b) a quench seen by one transducer is shown, and in (c) a quench seen by both transducers.

micron. When the second sound wave impinges on such a membrane, there is differential transmission of the super and normal fluid components. This causes the membrane to vibrate, and it can be used as the diaphragm in what is essentially a condenser microphone, or loudspeaker.

We have developed the OST transducers, and are now in a position to use them for cavity diagnostics. Figure 1, illustrates how we have tested the transducers in Toronto, by looking at the resonant frequencies of cylindrical pipe resonators with a driving OST at one end, and a driven one at the other. Figure 2 shows the first use of the OST for triangulation in a cavity test at TRIUMF.

Having successfully developed the second sound OST, we are now ready to move on to developing a spatially accurate system using first thick film SMD resistors, and then carbon resistors. Photographs of typical examples of both of these systems are shown in the budget justification section, and technical details are given there.

Highly Qualified Personnel

For this project we will have two summer students at Toronto, and two at TRIUMF.