Status of RF Superconductivity at Los Alamos National Laboratory

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Introduction

The Accelerator Technology Division at Los Alamos National Laboratory has been pursuing rf superconductivity for over 6 years. The intent is to have an in-house capability to apply superconducting technology in high-current light-ion accelerator applications which could benefit.

Original developmental work focused on single-cell elliptical cavity performance at 805 MHz and 3 GHz, to establish baseline parameters and demonstrate proficiency with contamination-controlled processing and assembling procedures. More recent work has concentrated on issues directly related to using superconducting cavities in intense proton beams. A 4-cell 805 MHz cavity has been ordered from Siemens and is presently being fabricated. The cavity will be used for testing multicell cavity performance, evaluating high peak power processing at 805 MHz, addressing instrumentation issues, and eventually for conducting a horizontal beam test.

Status

Single-cell cavity tests at 805 MHz

Single-cell cavity testing at 805 MHz is being used to establish baseline performance for superconducting cavities at this frequency as well as to evaluate new processing techniques for obtaining gradient and Q levels more reliably. Figure 1 is a histogram of maximum peak surface electric fields obtained from individual cavity runs at 2 and 4 K. Figure 2 shows a collection of characteristic Q_0 vs E_p curves along some typical high-current proton machine specifications, to demonstrate that a majority of runs meet these specifications.

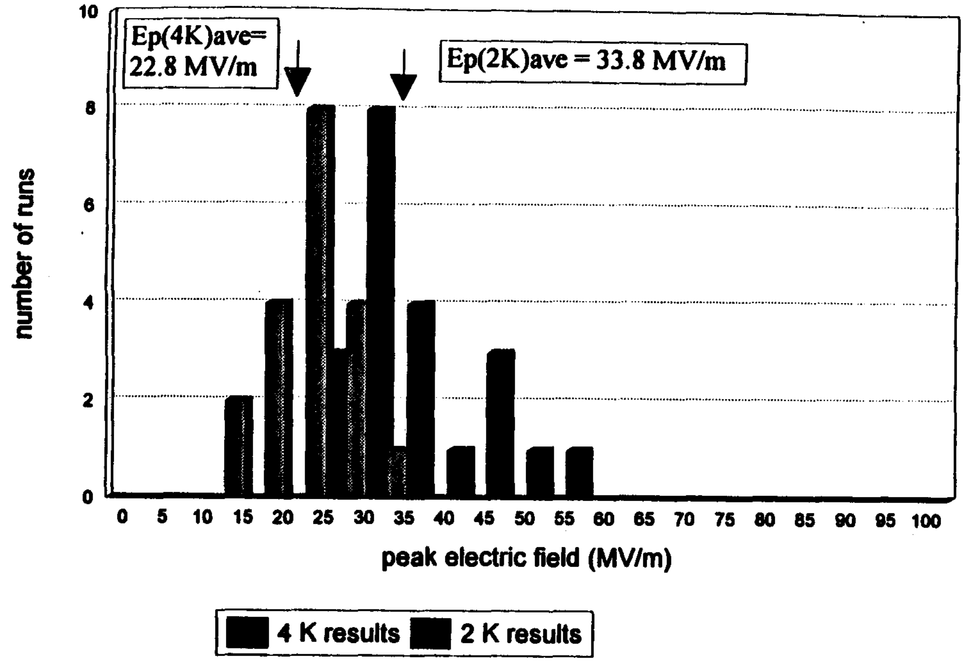

Fig. 1 Performance distribution for 805 MHz single-cell cavities at 2 and 4 K.

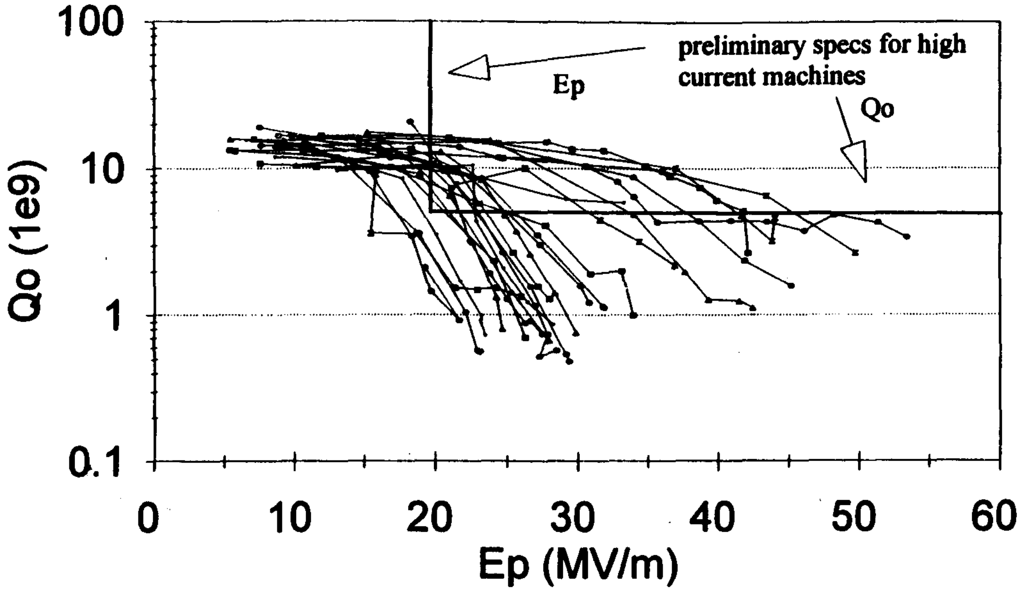

Fig. 2 Collection of characteristic Q_0 vs E_p curves for 805 MHz single-cell cavities run at 2 K. Note how a majority of the runs meet the preliminary specification.

Cavity processing has been developed and evaluated with the goal of recovering cavity performance after contaminating events, e.g., leaks and disassemblies, without chemical polishing. Though polishing is necessary to remove fabrication stresses and rough surface finishes, it has limited effectiveness in removing particulates.[1,2] These limits combined with the highly corrosive and hazardous nature of the polishing mixture have led to a search for alternate ways to recover cavity performance that are less noxious and less infrastructure intensive. Toward this end, high-pressure water rinsing and clean wiping have been tested on a limited basis and have shown some success.

High-pressure water rinsing is done with a deionized water-compatible stainless steel pump by Haskel that delivers up to 200 bar at 10 l/min. The final filter on the system is 5 μm. For high-pressure spraying of niobium, the pressure is set to 50 bar with a flow rate around 10 l/min. This pressure was chosen to avoid the microdislocations observed on heat-treated niobium samples when 10 μm of the surface was removed by buffered chemical polish (BCP) after high-pressure rinsing at 70 bar and above.

High-pressure water proved to be effective in removing particulates from niobium surfaces and did increase cavity performance in approximately two out of three tests. Figure 3 shows sequential tests of a cavity after it was contaminated by a leak to room air. The first curve is the cavity performance after the leak with no cleaning. The cavity was heavily field-emission limited and performed poorly. The next two curves represent data taken on a cavity that was high pressure spray rinsed after a leak, then assembled. There was roughly a factor of two improvement in performance. The last two curves represent data taken after the cavity was rinsed with high-pressure again and all ancillary components were cleaned with high-pressure water. The performance was increased another 50-70%. Though limited in number, the results are encouraging in that it appears the more the cavity is cleaned, the better it performs.

Limited testing was also done with clean wiping a cavity with a Texwipe Alpha 10 clean room wiper wetted with Omnisolve HPLC-Grade methanol. In two out of three tests, cavity performance increased 30% after wiping, as shown in Figure 4. In addition, by examining the wipers, contaminating particles were found (approximately 3-5 particles from 50-100 μm in size). Though it is not clear how this technique could be applied to a multicell cavity, it does indicate that wiping is effective in removing larger surface particles, if done with care.

The above mentioned techniques have been primarily used for cavity cleaning. Though cleaning the cavity surface is acknowledged as being an essential step in obtaining optimum cavity performance, it is also necessary to clean the ancillary components to keep the cavity surface clean during operation. Upon examining a cavity that was disassembled after a leak, particulates were directly observed (using grazing-incidence light) to be deposited in a circular pattern on the beam tube wall opposite the drive coupler port. It appears the electric fields in the drive probe assisted in particle transport. Finding these particulates also indicated the coupler assembly was not sufficiently cleaned. This has led to a much greater interest in cleaning the ancillary components, as well as the cavity, in order to achieve more consistency in cavity performance.

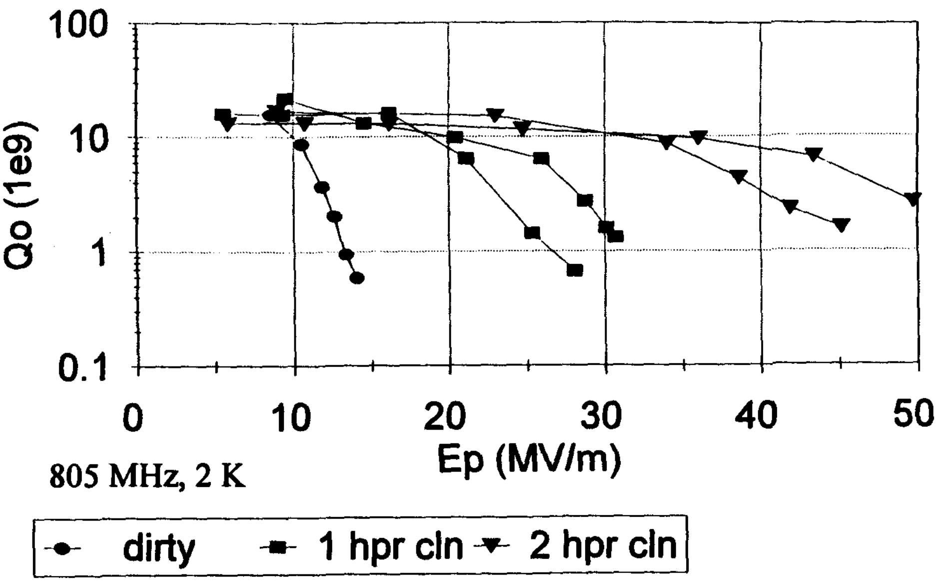

Fig. 3 Single-cell 805 MHz cavity performance. Solid circles represent a contaminated cavity with no cleaning, the squares represent a single cavity cleaning with high-pressure water, and the triangles represent multiple cavity cleanings plus parts cleaning with high pressure water.

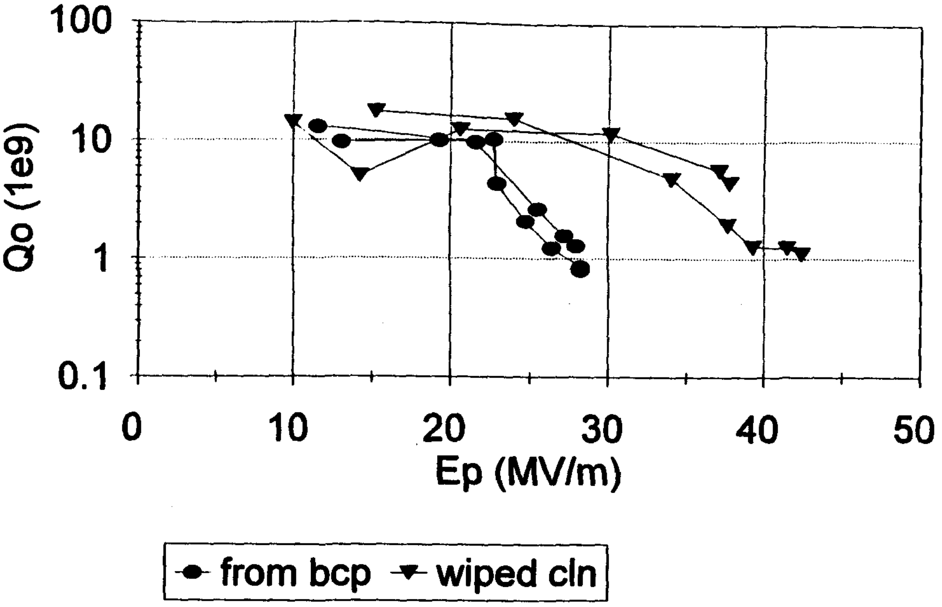

Fig. 4 Performance gains obtained by clean wiping a cavity. The gains that occurred in two out of three tests are shown.

Single-cell cavity tests at 3 GHz

In the interest of high real estate gradients, an experiment was conducted to test the effect of having a solenoidal field near a cavity, as shown in Figure 5. The idea was to approximate operational conditions for a cavity in a machine with strong focusing elements near by, where the cavity is in the superconducting state before the magnets are energized.

Energizing a strong magnet near a superconducting cavity poses two difficulties. First, as the field level near the niobium reaches the critical magnetic field, the niobium will go normal and rf losses increase dramatically, lowering the Q_0. This is complicated by the asymmetrical way the quench regions propagate down the beam tube. Second, if the cavity were to have an rf-induced quench in the presence of a static magnetic field, a portion of the field in the region of the quench will become trapped flux when the material goes superconducting again.

Overall, it was observed that the cavity Q_0 degraded as the magnetic field increased and drove the beam tube normal down its length. Small coils were used to evaluate flux penetration down the tube length and it was found that the penetration was asymmetric. For an rf quench in the cavity, it was observed that for a static magnetic field of 200-300 Oe at the equator, the Q_0 decreased by a factor of 5 per quench event. Subsequent rf quenching with the magnet turned off did not increase the Q_0 by releasing the trapped flux. The cavity only obtained its expected BCS Q_0 at 4 K after it was warmed to 15 K for 20 seconds.

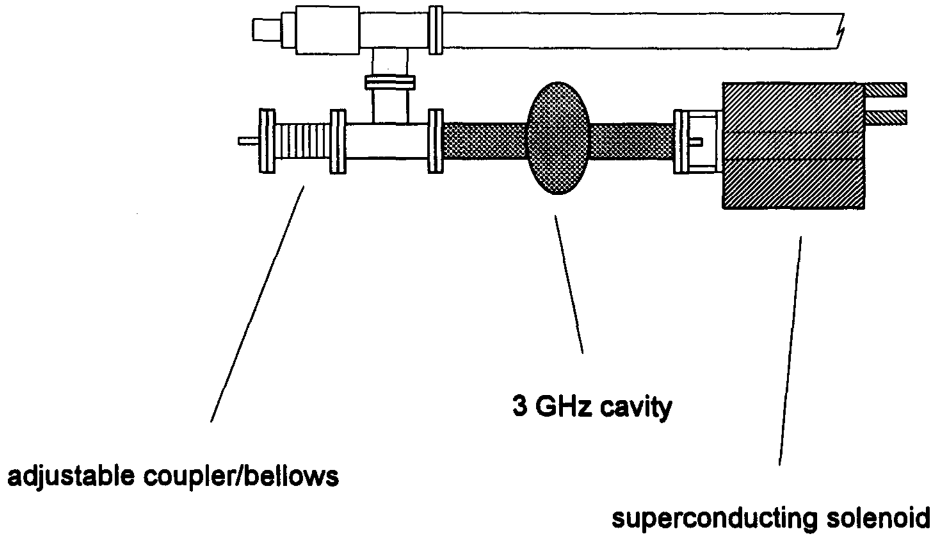

Fig. 5 Schematic showing magnetic field test on a 3 GHz cavity using a superconducting solenoid.

Multi-cell cavity tests at 805 MHz

In order to gain experience with multicell cavities, a 4-cell cavity was designed. This cavity was originally designed with seven cells for use in pion acceleration[3] but was shortened to four cells for use in existing facilities and to make it more compatible with high-current proton applications. The cavity is a fully stiffened structure with titanium bars to mitigate microphonic problems. It has double-sided heat-treated cells for improved RRR, has niobium hafnium alloy flanges that are compatible with Helicoflex seal use and high-temperature oven treatment, and is fully tunable to obtain field flatness to 5% with a tuner that has zero backlash.[4] The cavity is being fabricated by Siemens, and delivery is due early next year. Figure 6 is an engineering drawing of the cavity that shows the stiffening and tuning scheme.

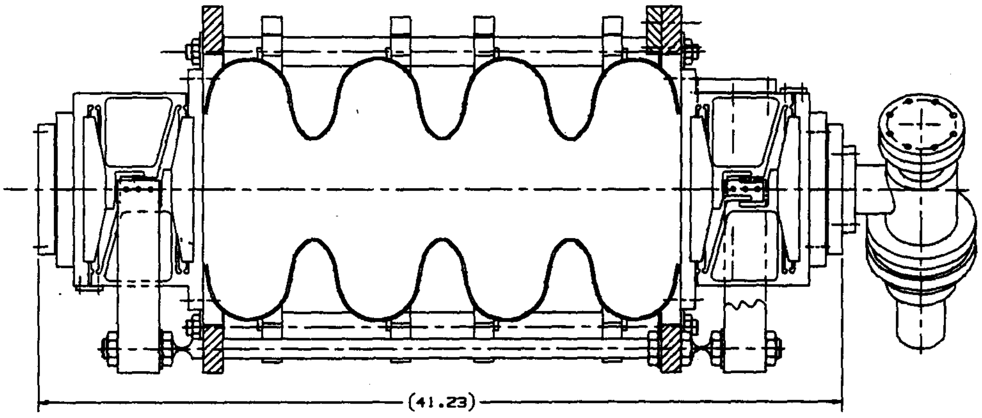

Fig. 6 Engineering drawing of a 4-cell 805 MHz cavity, showing the stiffening scheme and tuner.

Window and coupler development

To test high peak power processing on the 4-cell cavity, a cold coaxial window and coupler assembly have been designed and fabricated. The coupler is adjustable, employing a sliding choke joint, and has a Q_{ext} range of 70 dB.[5] The window has been measured in a transmission-line setup to have a VSWR of 1.02 at 805 MHz at room temperature. The coupler has a VSWR of $\leq$ 1.05 over a bandwidth of 44 MHz. Figure 7 is a drawing of the window and coupler assembly.

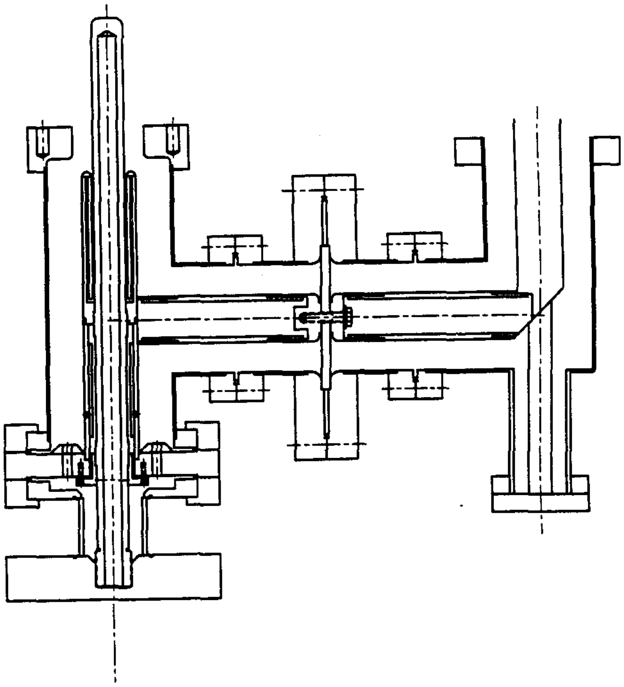

Fig. 7 Drawing of a coaxial window and coupler assembly, that uses a choke joint to allow adjustment.

Plans

Testing the 4-cell 805 MHz cavity is our primary short-term goal. Designs are completed and fabrication is underway for a vertical test insert, diagnostics, and handling fixtures. Initial testing is to verify that the cavity meets its specifications of an average accelerating gradient of 5 MV/m at a Q of $\geq 2 \times 10^9$, with longer-range plans of doing advanced cleaning on the cavity to improve performance.

In the interest of being able to deliver a complete superconducting accelerator design for light-ion applications, mid- and low-beta structures will be developed. Specifically, initial engineering work has begun on flattened elliptical structures to assess structural issues, and conceptual work is in progress on low-beta structures. In addition to the low-beta work, a superconducting RFQ is being fabricated, to test field performance issues in an all-niobium vane-type device.[6,7]

To evaluate optimum applicability of rf superconductivity for high-current light-ion applications, system studies are envisioned to evaluate the numerous issues relevant to these applications. Work is in progress to evaluate applying superconducting technology for use in ATW, an intense deuteron accelerator concept for waste transmutation.[8]

Conclusion

Los Alamos is progressing toward working with multicell 805 MHz cavities. This work is a necessary step in applying superconducting technology to intense-beam applications using light-ions. Efforts are underway to develop mid- and low-beta structures to enable complete superconducting accelerator designs over wide beta ranges. In addition, system studies are necessary to determine optimum applicability of superconducting technology to intense-beam applications. Finally, work is continuing toward developing cleaning processes for contaminated cavities that will increase cavity performance with higher reliability and simplify recovery processing.

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