SUPERCONDUCTING HILACS*

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We wish to report briefly on the progress of the Caltech study of the feasibility of building a superconducting hilac, and then to mention some points to stimulate further discussion.

I. We have concentrated on using helical waveguides as accelerating structures, the properties of which have been discussed extensively elsewhere.[1] Specifically, we are studying shorted half-wave standing wave resonators, which have an interesting property not exhibited by long helices. Because of their non-ideal termination, the frequency of these resonators is 10% to 25% higher than predicted for an ideally terminated waveguide. However, the electric field along the axis is distorted into an almost perfect full sine wave, as shown in Fig. 1.[2] Thus, the effective phase velocity of the wave is reduced by 40% to 50% from the velocity of the wave on an infinite helix of the same pitch angle. This characteristic simplifies the acceleration of very low velocity heavy ions.

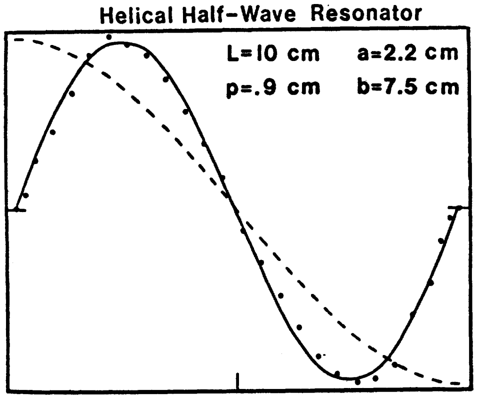

Fig. 1. Longitudinal electric field on the axis of a $\lambda/2$ helical resonator. The dashed line is the field profile for an ideally terminated section. The points are measurements of the field in a resonant cavity (2), and the solid curve is a sine wave fit to the experimental points.

A normal or superconducting accelerator formed of a series of these cavities, phased independently, will accept quite a broad range of e/m values. Particles differing in velocity by a factor of two will be accelerated 90% as efficiently as a particle traveling at the velocity of the wave in the cavity. Particles with a factor of three difference in velocity will be accelerated at 80% efficiency. This means e/m values differing by a factor of eight will be accelerated at least this efficiently.

Because of the much greater ease of fabrication, we are working with lead-plated copper resonators. Many of the engineering and reliability problems associated with superconducting accelerators do not strongly depend on the material used. If it becomes clear at some future date that niobium is definitely superior to lead, the changeover will be relatively straightforward.

Along with the usual problems of achieving high field levels and low losses, the helix presents several unique difficulties. The complex geometry encourages multipactoring, and several levels have been observed. The action of the electromagnetic field on the relatively flimsy coil causes very large static frequency shifts, and can result in unstable mechanical oscillations coupled to the electromagnetic field.

Our experiments have been performed on 53 Mhz cavities which are 20 cm in diameter, with a 15-cm diameter, 12-cm long coil made of 1-cm tubing. Peak magnetic fields of about 300 gauss (corresponding to a possible energy gain for a singly-charged particle of 2 MeV/m), and surface resistances of less than 10^{-8} ohm have been observed.[3] Several multipactoring levels occur, up to about 30 gauss field levels. These levels are normally passed by distorting the electron paths by superimposing a higher frequency resonant mode. It is also possible to drive through these levels by coupling power into the cavity faster than it is absorbed into electron current. Both methods have worked, but neither has been completely reliable.

We have recently begun treating the distortion problem by introducing longitudinal sapphire supports. We have found the loss angle of such crystals to be less than 2×10^{-7}, and the filling factor is low enough so that there are only very small losses introduced by the dielectrics. In a preliminary test to determine the effect of these supports, three sapphire rods were fastened to the inside surface of the helix by tying them to the helix with teflon thread sealing tape. Even this very crude support reduced static frequency shifts by more than an order of magnitude. No new multipactoring levels were observed in tests up to 150 gauss field levels. The cavity was sufficiently stiffened so that it could be excited to a 50 gauss field level while phase-locked to an external oscillator. The problem of electromechanical instabilities, which is an artifact of a too slow response time of the feedback system, was eliminated by using a very wide band width amplifier. Figure 2 shows a signal from a cavity excited to about 270 gauss. Figure 3 shows a signal with larger amplitude. Initially, the cavity reaches a multipactoring level. The addition of a higher harmonic, which is visible on the oscilloscope trace, bypasses the level. At an excitation greater than 300 gauss, a "soft" limit is reached, where the losses increase by an unknown process. The decay is quite rapid down to a multipactoring level, after which the small signal Q is again exhibited.

II. It would be worthwhile to have more discussion and thought about the type of heavy ion accelerator that would be most useful. What will be done with energetic heavy ions? Usually, much emphasis is placed on the production of nearly stable superheavy nuclei. One suggested way of doing this is the acceleration of very heavy ions ($A > 200$) to bombard similar nuclei, with the desired products possibly resulting from fission of the compound nucleus with $A > 400$. Calculations by Nix[4] indicate that this may neither be the most efficient nor perhaps even a possible method of producing superheavies. He feels lighter ion beams, such as of ^{48}Ca or ^{76}Ge may be more suitable for reaching the

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island of stability. There is also much interesting physics and astrophysics in the study of nuclei far from the beta stability line, a region which again may be more easily reached by using lighter ions as projectiles.

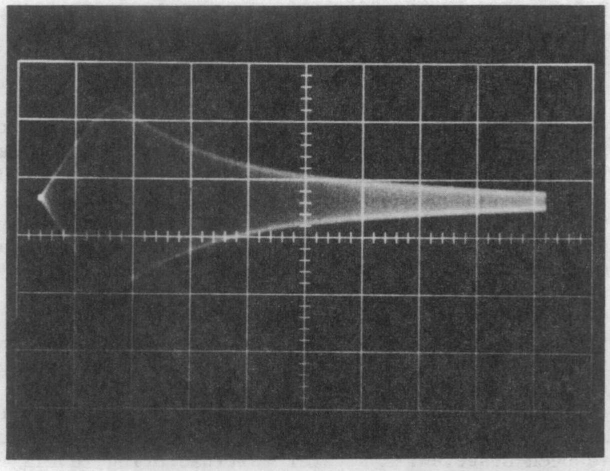

Fig. 2. Excitation and decay of resonance in a 53 Mhz helical cavity. The maximum field is about 270 gauss (3).

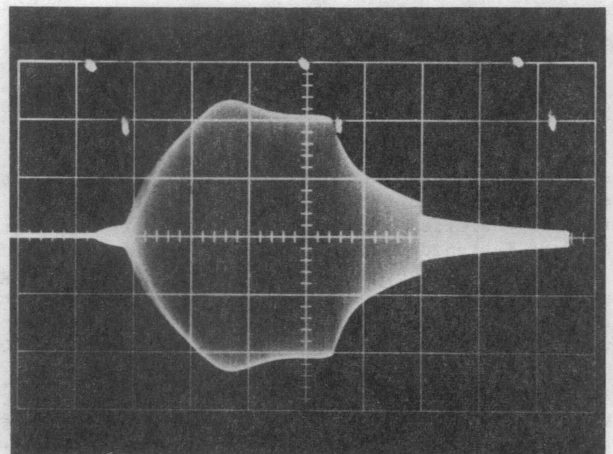

Fig. 3. Excitation of the same cavity to higher field levels, showing multipactoring and limitation due to increased losses. The maximum field is about 300 gauss (3).

Considering the uncertainties, ideally one would want an accelerator which operated efficiently over the mass range A = 1 to 250. However, it is possible that such a device might be difficult to obtain. A machine with a more limited range ($A \lesssim 100$) might be nearly as useful, and much cheaper. It would be worthwhile to define more clearly the type of tool we want.

There has been some discussion recently about using alternating phase focusing for new linacs. Since we have been partly responsible for this talk, we should ask whether this method has any advantage for hilacs. The two main advantages of this method of phasing are improved energy resolution, and no need for additional focusing lenses. This latter point is very important for superconducting machines, because of the problem of high magnetic fields produced by magnetic lenses. But, there is also some interest because of the difficulty of magnetic focusing at the low energy end of normal hilacs. The disadvantages of alternating phase focusing are that one can only accept a 5% pulse length, and one needs an injected beam with very low velocity spread in a very short bunch. It is not clear that the heavy ion sources necessary to get large beams in a high charge state will necessarily have low enough internal energy spreads to allow the efficient formation of such tight bunches with sufficiently low associated velocity spreads. The standard stable phase accelerating system, at the cost of introducing external focusing and having intrinsically poorer energy resolution, can accept 25% of an unbunched beam and will tolerate a much larger energy spread from the ion source. Since it is not clear that currents from heavy ion sources will be large enough that we can throw away most of the output and still achieve sufficient beam intensity, it will probably be necessary to take all the phase space volume one can get. This requirement gives a stable phase accelerator an enormous advantage. Also one can improve the energy resolution of a stable phase accelerator by suitably restricting the phase of the pulses. However, there is no way one can increase the acceptance of a variable phase focused device.

Another point to consider is over what energy range a linac is a good method for accelerating heavy ions. Since it has the ability to accelerate higher beam currents than a cyclotron, it appears to be useful up to a value of about 10 MeV/nucleon for very heavy ions, before becoming unwieldy. (For light ions, 100 MeV/nucleon could possibly be achieved with the same sort of restrictions.) There may be a desire to go even higher, possibly to about 1 GeV/nucleon for cosmic-ray studies and medical therapy. To reach this range some other type of structure, possibly a synchrotron or ERA will be more practical.

We now come to the question: "Is there any clear advantage to using a superconducting hilac?" The strong proposed advantages of a superconducting electron linac are simultaneous high duty factor and high gradient. Present normal conducting hilac designs already use duty cycles of 25% to 100%. Superconductivity cannot improve stability or energy resolution, because pulsed operation is already eliminated. The energy gradient of present normal accelerator designs is from 1.5 to 2 MeV/m. The best that can reasonably be hoped for from a superconducting hilac is about a factor of two higher. One can only make very qualitative comparisons of costs, as the costs of a superconducting machine cannot be reasonably estimated at this time. As far as capital costs go, there can be little advantage to a superconducting machine, because the largest expense, the target and experimental facilities, will be the same. The accelerating structure will possibly be shorter for a superconducting machine, but almost certainly will be more expensive per unit length. RF high power sources cost more for a room temperature machine, but this is at least partially offset by the expense of the refrigeration and Dewar systems of the superconducting design.

Considering operating costs, it is possible that the superconducting refrigerator power is cheaper than the RF power of the normal machine; however, we must also consider reliability. The long term reliability of a normal accelerator can be estimated quite well, but one cannot even guess at the reliability of a superconducting machine. There are strong reasons to believe that its utilization would be less efficient because there are so many more things that can go wrong. One knows almost nothing of the long term stability or lifetime of superconducting resonators.

We are interested in a heavy ion accelerator as a tool for investigating the physics of certain heavy ion-induced reactions. We should certainly be looking for the quickest, cheapest, and most reliable way to build this tool. A superconducting hilac with the best imaginable properties at the present time still offers only marginal advantages over a room temperature hilac. With much worse performance distinctly possible, what strong justification can be offer for pushing development of a superconducting hilac?

References

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