CRYOGENIC STUDIES OF RF ACCELERATING STRUCTURES, VINTAGE 1978*

D. Liska, J. Uher, J. Potter, AT-4, MS H821
Los Alamos National Laboratory, Los Alamos, NM 87545

Summary

Cryogenically cooled rf cavity studies were undertaken at Los Alamos in 1978 to test the effectiveness of reduced temperature on the Q-enhancement of 450-MHz drift-tube linac structures. A complete facility was set up to do high power tests, not only at liquid nitrogen (LN_2) temperature but with liquid hydrogen (LH_2) as well. The cavity, Dewar, klystron test stand, and a remote outdoor enclosure were constructed. Hydrogen safety approval for the tests was obtained. Unfortunately, the hydrogen tests were never done. However, the cavity was tested at high power in LN_2 and a Q-enhancement of 2.02 was recorded, compared to 2.7 expected theoretically. This work is now continuing with improved measuring techniques using some of the same apparatus. It is the purpose of this paper to report on the early work and to reference its continuation today.

Description of Experiment

Because testing at LH_2 was the object of the 1978 tests, a vacuum-walled fiber-glass Dewar was constructed to house the cavity, as shown in Fig. 1. Liquid hydrogen has a relatively high latent heat of vaporization, and a Dewar of this sort would have been adequate to contain the boil-off at high rf power. More recently, attempts to use this cavity and Dewar with liquid helium have failed because of thermal losses of the Dewar. Liquid neon will also work in this Dewar, but the excessive cost of this cryogen makes its use impractical in anything other than closed-loop systems.

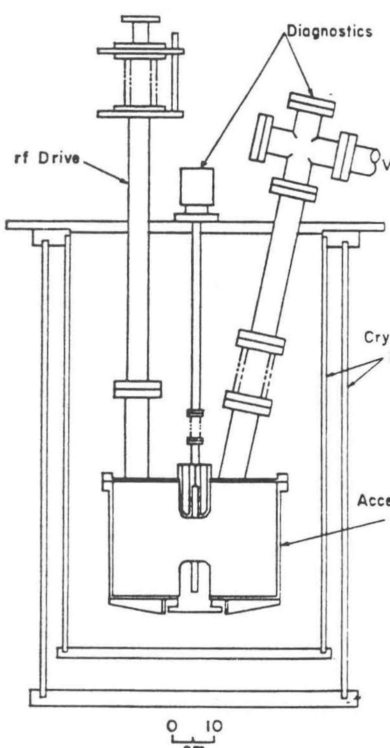

Fig. 1. Cryostat and cavity for low temperature studies.

The cavity itself (Fig. 2) is a demountable, brazed OFHC assembly with all coupling ports attached to the cover. A 1.625-in. drive line is provided with a coupling loop radially oriented. Penetration adjustment under vacuum is permitted by an external bellows. An electric field probe, also adjustable, is provided in the cover drift-tube bore. Finally, a vacuum pump-out and diagnostic port is attached to the cover at an angle so that x-ray views off the bottom drift-tube nose can be obtained. The seal between the cavity cover and body is an oversized conflat that serves both as an rf and a vacuum seal. This seal has proved to be marginal from room temperature to LN_2 (77 K) and is probably inadequate down to LH_2 (20 K).

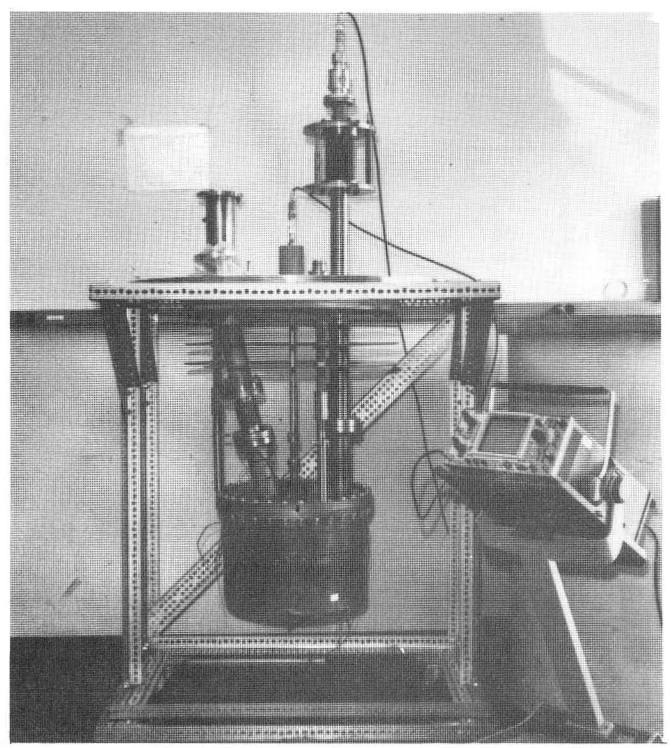

Fig. 2. Demountable 450-MHz test cavity.

The experiment was housed in an open enclosure near the electronic test lab building (ETLB) at LAMPF where the early testing was done. A 60-m, 3.125-in. coaxial drive line was suspended over a driveway to connect the cavity to the klystron test stand. Many safety precautions had to be taken because the purpose of the experiment was to test the cavity in 150 ℓ of LH_2. The Dewar was sealed and the boil-off gases were vented to the atmosphere above the enclosure roof through relief valves sized to handle rapid boil-off. The Dewar was supported 2 m above all electrical contactors and outlets, and the enclosure was well ventilated to prevent collection of an explosive mixture of hydrogen and air. Hydrogen detectors were provided to give warning well before explosive levels were reached.

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Physics Expectations

Despite the state of readiness, the LH_2 experiment was never conducted because of funding cuts. The experiment in 1978 was conducted before spaceborne accelerator systems that could benefit from large Q-enhancement were defined. Large Q-gains were anticipated, however, as indicated in Fig. 3. Conservative estimates at LH_2 predicted 8.3:1 over room temperature at 450 MHz. More recent results to be reported in a later paper indicate that such a large Q-gain may be difficult to obtain in real drift-tube linac cavities and factors of roughly half the anticipated value might be more realistic.

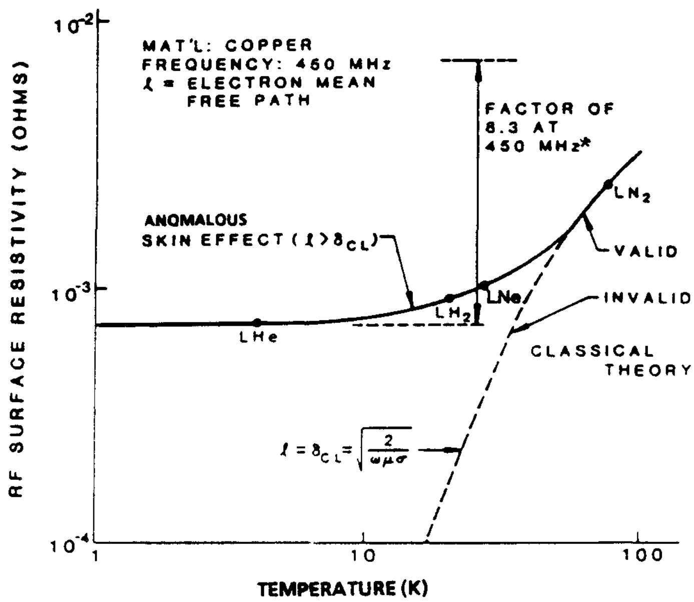

Fig. 3. "Anomalous skin effect." Deviation of resistivity from classical theory at low temperatures.

Copper exhibits behavior at low temperatures, which benefit the designer of rf structures. The anomalous skin effect in Fig. 3 gives a considerable, if not theoretical, Q-enhancement. The thermal conductivity is improved (at 450 MHz) by a factor of about 25 times. This helps the material pass the skin-depth thermal energy through the wall to the cooling jacket more readily. The coefficient of thermal expansion is also reduced by a factor of about 70 times. This makes the structure extremely stable in frequency over a wide range of power levels and duty factors.

Test Results

Tests were performed at LN_2 on the 450-MHz demountable cavity and compared with room temperature. The coupling coefficient for the loop was set to β = 1.90 undercoupled at room temperature. This coupling changed to β = 1.08 overcoupled as the temperature was dropped to LN_2. The technique used to determine Q-enhancement utilized measurements of the Voltage Standing Wave Ratio (VSWR) as frequency was varied around resonance. To use this method accurately, it was necessary to sweep the frequency to the half-power points on either side of resonance. This limited the maximum power that could be delivered by the loop to 29 kW peak. The half-power VSWR was determined from the following formula:

$$\mathrm{VSWR}_{1/2} = \frac{1 + S_o + S_o^2 + (1 + S_o)\sqrt{1 + S_o^2}}{S_o} ,$$

where S_o = VSWR at resonance.

The unloaded Q is determined from the coupling coefficients and half-power points:

$$Q_o = Q_L\ (1 + \beta),$$

where

$\beta = S_o$ (overcoupled),

$\beta = S_o^{-1}$ (undercoupled)

$Q_L = \omega_o/\Delta\omega_{1/2}$,

ω_o = resonant frequency, and

$\Delta\omega_{1/2}$ = half-power frequency spread.

The results of the tests are shown in Table 1. The 29 kW of peak rf power was delivered in pulses 150 μs in length and at 0.6% duty factor. The Q-gain was only 2.02 compared to 2.7 theoretical. Because the cavity is demountable with several large penetrations on its end wall, some Q degradation is expected, but the low figure of 2.02 shows also that the VSWR technique, with its large frequency swings, is not a good method to use.

TABLE 1
1978 TEST RESULTS

Test	Q_L	β	Q_o Undercouple	Q-gain Overcouple
Room Temp/Hi pwr pulsed	12 445	1.90 (under)	18 995	
LN_2 Temp/Hi pwr pulsed	18 500	1.08 (over)	38 425	2.02

More recent test results on this cavity showed higher Q-enhancement. The modern technique used an overcoupled loop at LN_2 and sensed phase changes between incident and reflected voltages as frequency was stepped slightly (a few kilohertz) around resonance. This technique is also preferred for measurements into the anomalous skin effect region.

Conclusions

The VSWR test method used in 1978 on the cryogenic cavity showed a Q-enhancement of only 2.02 at LN_2. Tests were never conducted at LH_2 and the same method would have been misleading if they had. Modern phase shift techniques providing better results are now being utilized. This paper has attempted to describe the early history of this project and to indicate that it is continuing, with new results to be published in the future.