Proceedings of SRF Workshop 1984, Geneva, Switzerland

SRF84-25

LONG TERM OPERATION OF NIOBIUM SUPERCONDUCTING RESONATORS IN THE ARGONNE HEAVY-ION LINAC*

K.W. Shepard

Argonne National Laboratory, Argonne, IL 60439

INTRODUCTION

This paper describes some of the effects observed in operating superconducting resonators over long periods of time at high field levels. The resonators are the niobium split-ring resonators which form the Argonne superconducting heavy-ion linac [1], and the period of operation considered extends from initial operation in 1978 to the present and includes more than 17,000 hours of operation with beam [2,3].

In what follows, first a brief description of the resonators and operating procedures is given. Then, the on-line performance of all the resonators in one cryostat module over a period of several years is reviewed and disucssed. Finally, the nature and causes of performance degradation in several (atypical) resonators are examined.

RESONATORS AND OPERATION

The resonators discussed are niobium split-ring resonators of two types: type L, of optimum velocity $\beta_o = .066$, and type H, of optimum velocity $\beta_o = .105$ [1,4]. Both types are 16 inches in diameter and operate at 97 MHz. The peak surface electric field is 4.8 times the accelerating field. The high-field portions of the resonators are constructed of standard grade niobium and vacuum annealed at 1250°C. Prior to operation, the resonators are

*Work performed under the auspices of the U.S. Department of Energy.

prepared by electropolishing and then rinsing with water and methanol. Rinsing and assembly is performed in a laminar-flow, class 100 clean room.

For both off-line tests and on-line operation the resonators are baked at 80-90 C in a vacuum of typically less than 5×10^{-7} torr for 24 hours prior to cooldown. The vacuum at the room-temperature wall of the cryostats is typically less than 10^{-8} torr when the resonators are cold (<4.7K).

Initially upon cooling, the resonators exhibit low-level multipacting (mp) barriers which are eliminated by the application of a few watts of rf power over a period of one to several hours. Finally, the resonators are helium conditioned by either cw or pulsed operation at as high a field level as possible in the presence of approximately 10^{-5} torr of He gas [5,6]. Usually, no subsequent conditioning is required unless the resonators are warmed above 77K.

ON-LINE RESONATOR PERFORMANCE

Figure 1 shows the actual operating field levels for two L-type resonators in the first cryostat module of the linac.

Over the period of time shown, the cryostat was warmed to room temperature several times each year, and vented to atmosphere typically once per year. For more than 90% of the time the resonators were under vacuum and at 4.7K.

The operating levels shown are determined by a number of factors, some of which have nothing to do with the intrinsic resonator properties: thus the numbers shown represent a lower bound on the resonator capability at any given time. E.g., for about one month in mid-1983, the operating fields were limited to ~ 2MV/m by a failure in the liquid helium plumbing which reduced coolant flow to all of the resonators in the first cryostat.

In late 1981 and early 1982, operation was frequently limited at ~ 2.3 MV/m by a multipacting barrier in the L-type resonator. The barrier was probably caused by an air leak into the resonator vacuum which was present at that time. We have frequently observed that the condensation of air, or of N_2 gas, on the resonator interior will cause multipacting.

Often, when performance has been found to decrease over a period of several weeks, He gas conditioning will restore or increase the operating field level. Performance decrease requiring conditioning has frequently been associated with vacuum accidents or malfunctions.

PERFORMANCE DEGRADATION

Effect of Catastrophic Vacuum Failure

Figure 2 shows the effects observed in a typical resonator of four H-type resonators that were exposed to sudden vacuum failure while at 4.7K. The vacuum accident was caused by failure of a metal bellows on the liquid helium system, and ~ 25 liters of liquid helium were suddenly dumped into the vacuum space. The data shown in Figure 2 were obtained in off-line tests.

When new, the resonator performed as shown in the test of 3/17/79. The test of 11/1/78 shows performance immediately after the helium accident which exhibits a substantial decrease in resonator Q, and also heavy electron loading at reduced field levels. The test of 11/12/78 was made after electropolishing the resonator to remove 15 μ of niobium from the original surface. Although performance is partially restored, it is clear that the original surface has not been re-established, and that damage to the metal is surprisingly deep.

The test of 1/31/79 shows performance following removal of a total of 25 µ from the original surface, and shows performance restored to better than the original level.

Effect of Surface Contamination

Figure 3 shows the results of off-line tests of an H-type resonator which exhibited performance degradation in the course of more than three years of operation in the linac. The test of 1/31/79 was performed just prior to installing the resonator in the linac, where it operated until late 1982. The test of 10/27/82 shows substantial performance degradation and a local minimum in Q at $E_a \approx 0.5$MV/m. Such minima have also been observed in resonators known to be contaminated with vacuum pump oil. Another possible contaminant would be small particulate matter.

The resonator was cleaned ultrasonically with water and detergent, then rinsed with water, trichloroethylene, and methanol. Subsequent testing (on 11/28/82) showed the performance to be restored. Thus, it is clear that performance had been degraded by easily removed surface contaminants.

CONCLUSIONS

Superconducting resonators have been operated at high field levels (surface $E \approx 17$ MV/m) and with beam over periods of several years. The data of Figure 1 demonstrates that niobium surfaces are stable with respect to both superconducting and electron-loading properties under such conditions.

However, surface contaminants of any sort usually cause temporary performance loss. In particular, the integrity of the resonator vacuum is of great importance for stability of operation.

REFERENCES

1. K.W. Shepard, C.H. Scheibelhut, P. Markovich, R. Benaroya, and L.M. Bollinger, IEEE Trans. Magn. MAG-15, p. 660 (1979).
2. L.M. Bollinger, IEEE Trans Nucl. Sci. NS-30, p. 2065 (1983).
3. R.C. Pardo, to be published in the Proceedings of the 1984 Linear Accelerator Conference.
4. K.W. Shepard, IEEE Trans. Nucl. Sci. NS-28, p. 3248 (1981).
5. H.A. Schwettman, J.P. Turneaure, and R.F. Waites, J. Appl. Phys. 45, p. 914 (1974).
6. C. Lyneis, Proceedings of the Workshop on RF Superconductivity KFK 3019, p. 119 (1980).

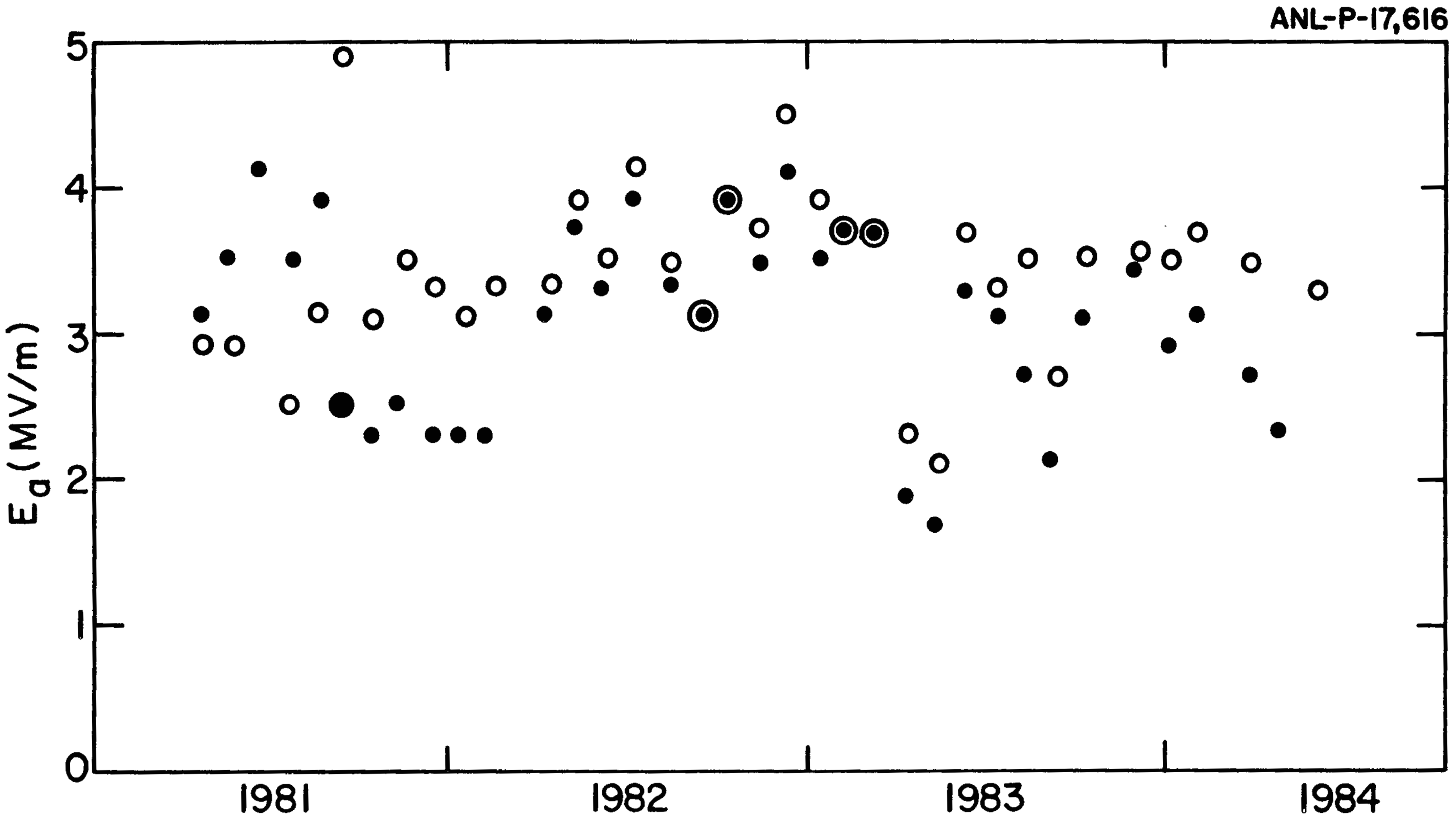

Figure 1 - Operating field levels for two L-type resonators over a three and one-half year period. The resonator length is 20.3 cm so that at E_a = 3MV/m, each resonator provides 0.61MV of effective accelerating potential. The peak surface electric field is 4.8 x E_a.

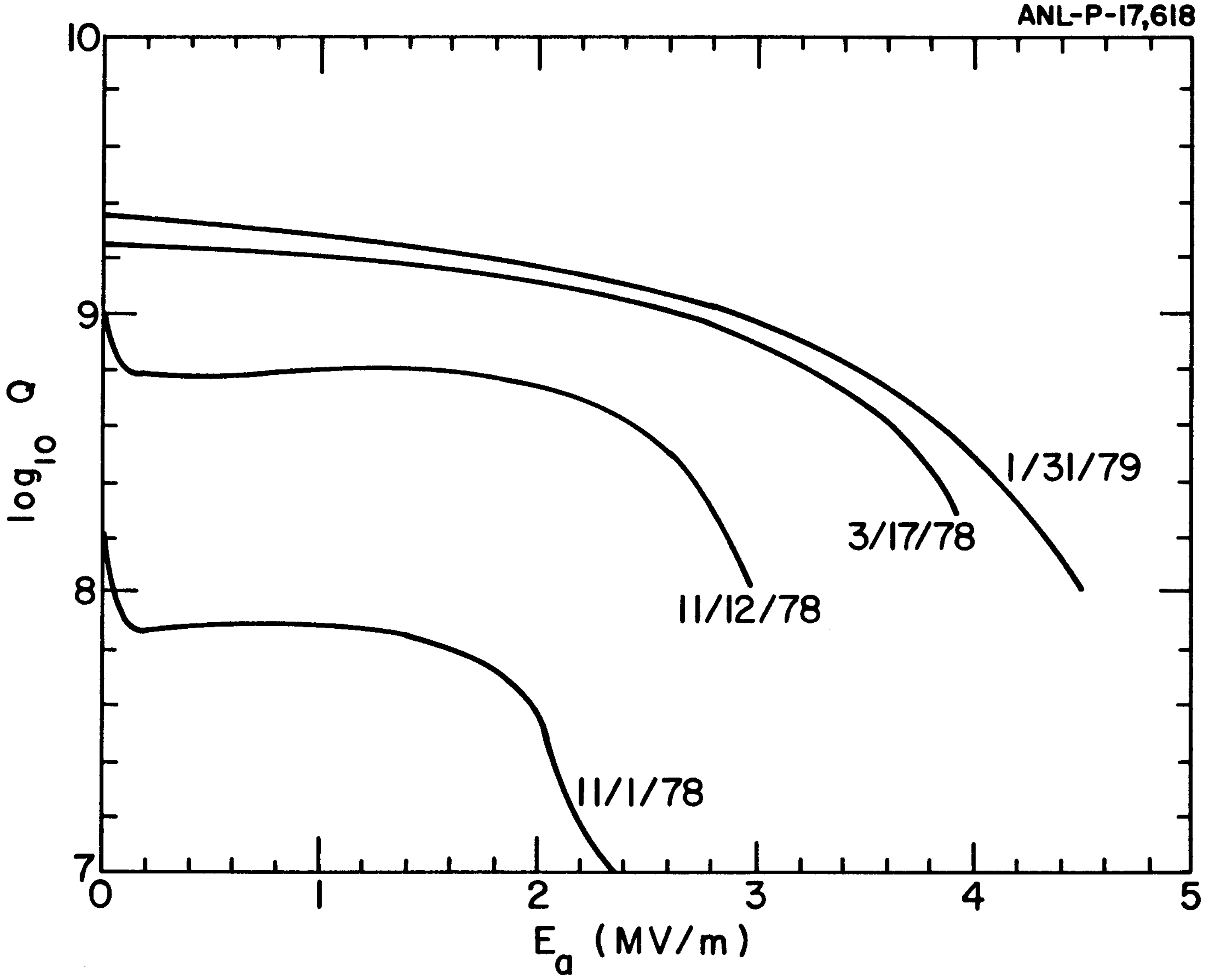

Figure 2 – Q vs E_a at 4.2K for a H-type resonator in chronological sequence: initial performance (3/17/78), after a catastrophic vacuum failure (11/1/78), after electropolishing 15 μ (11/12/78), after electropolishing 25 μ from the niobium surface (1/31/79).

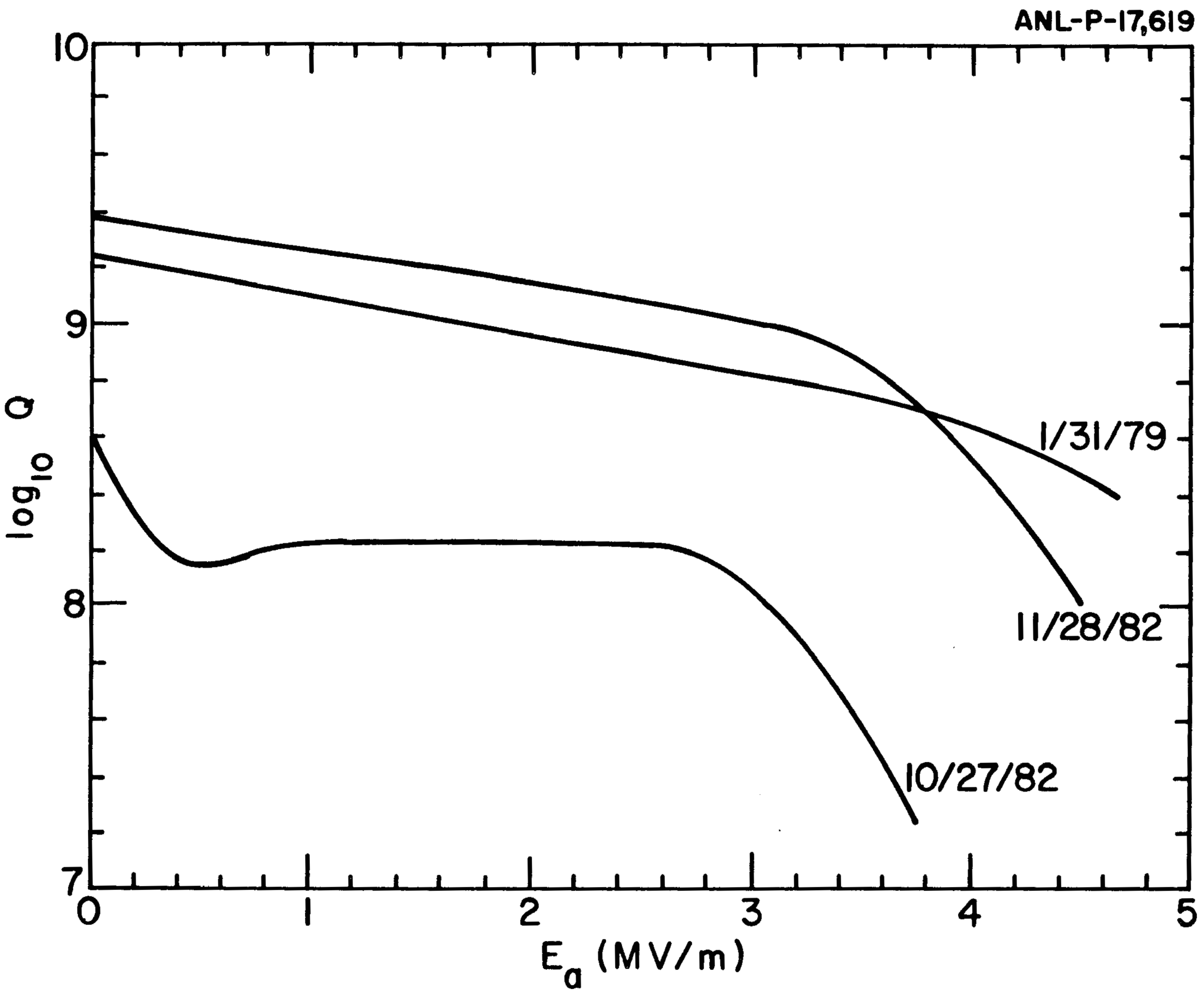

Figure 3 - Q vs E_a at 4.2K for an H-type resonator in sequence: prior to long-term operation (1/31/79), after operating on-line for three and one-half years (10/27/82), after ultrasonic cleaning with detergent and water (11/28/82).