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A HIGH-PERFORMANCE Nb HELICAL CAVITY

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A HIGH-PERFORMANCE Nb HELICAL CAVITY†

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ABSTRACT

A 92-MHz superconducting-Nb helix resonator of exceptional quality has been thoroughly tested under a variety of conditions. The unit is a full-scale $\lambda/2$ structure *with dimensions* appropriate for heavy-ion acceleration. When operated at a temperature of 1.8K and with bare (not anodized) Nb surfaces, the low-*field Q is* 9.4×10^9, equivalent to a surface resistance of 5×10^{-10} ohms. The maximum surface magnetic field is 1200 G and the maximum surface electric field is 37 MV/m, which corresponds to a traveling-wave axial accelerating field of 4.6 MV/m. These characteristics set new performance standards for helix resonators. A systematic study of the effects of various surface treatments, including abuses of the cavity, are described. The tests consist of 24 liquid helium cooldowns, at 4.2K and 1.8K, of the cavity with bare and anodized Nb surfaces which at various times were electropolished, oxypolished and heat treated. RF and helium conditioning are discussed as techniques to get through multipactoring barriers and extend the maximum obtainable electric field.

I. INTRODUCTION

In low-β helix structures, the max accelerating field is limited by electron emission. Surface defects cause large enhancement factors. Hence in principle, it is possible to reduce these enhancement factors and achieve higher fields. This paper is part of a systematic effort to increase this field, the highlights of which will be presented here.

Considerable work has been done at Stanford[1], Karlsruhe[2,3], and Argonne[4,5] to study the operation of superconducting Nb helical resonators for the purpose of ion acceleration. This paper is the result of experimental work performed over a period of 1.5 years on a single 92 MHz $\lambda/2$ Nb helical cavity labeled C. It is a systematic study of the effects of various surface treatments on C, including the simulation of vacuum accidents in a real superconducting linac. The tests consist of 34 liquid-helium cooldowns of C with bare and anodized Nb surfaces which at various times were electropolished, oxypolished, and heat treated.

II. RESONATOR GEOMETRY AND EARLY HISTORY

Figure 1 shows C assembled. It is an all Nb unit distinguished mainly from other helices by the small value 2 for the ratio of the can diameter to helix diameter. Indium seals are used to insure proper vacuum and RF continuity between cover plate and the cylinder with a tongue-in-groove seal and there is no attempt made to form a Nb to Nb seal. The small size of the cylinder has made it easier to handle and has added much to its vacuum reliability. The two adjustable Cu RF probes are situated mid point between the helix ends where the electric field is at its maximum for efficient coupling and where the magnetic field is minimum thus reducing eddy current losses on the probes.

At low fields, Q_0 (the unloaded Q) was determined by the decay method. Also, the power loss P and the change Δf in resonance frequency was measured. These data allow one to determine the constant c in the relationship

$$PQ_0 = c\Delta f. \tag{1}$$

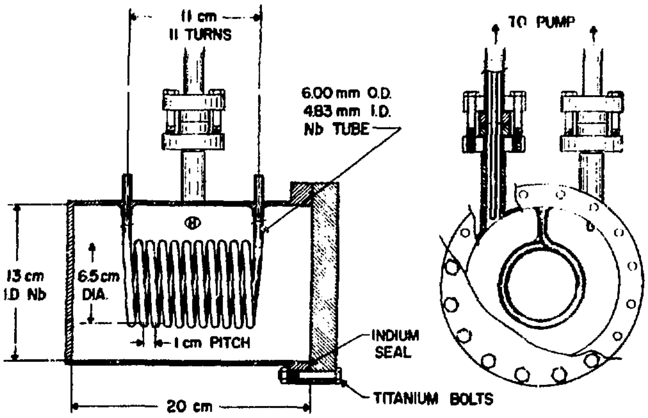

Fig. 1. Helix C structure.

For helix C, we also have the expression

$$E_{ax} = 2.5 \times 10^{-4} \sqrt{PQ_0}, \tag{2}$$

where E_{ax} in MV/m is the energy gain (calculated from the field distribution in a warm cavity) divided by the length of the helix. This definition is made by analogy with what could be calculated for a very long resonator made up of a succession of $\lambda/2$ sections in which the velocity change through the resonator is small. By combining (1) and (2), we have:

$$E_{ax} = k \sqrt{\Delta f}. \tag{3}$$

Thus at higher fields we need only know Δf and P to determine E_{ax} and Q_0 by means of (1) and (3).

The helix and outer shell of unit C were given separate treatments. The outer shell was made from two semi cylinders which were electropolished individually. The helix was electropolished by itself, then heat treated twice for 5 hr at 1250°C as a resistance element in a vacuum furnace. The two cylinder halves and the helix were electron-beam welded together. Ten conditions of resonator surfaces were studied following this initial assembly, with the surface condition being established by the electropolishing and/or oxypolishing treatment administered before each test. The results of these early measurements were disappointing. In the test†† on cavity C_1 the maximum field was only 1 MV/m at a Q_0 of 2.3×10^7. C_2 was just as bad. As a result, techniques were slightly altered. C_4 was oxypolished and anodized again. A clean room with laminar flow of filtered air was used and clean room rules were adopted for the assembly. A max E_{ax} of 2.5 MV/m was reached with a Q_0 of 6.4×10^7. This was a vast improvement over C_2, but still not as good as the performance of other resonators being tested.

Since the cylinder had never been heat treated,

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††In the following we designate the unit formed for the n^{th} surface preparation as cavity C.

the whole unit was now heat treated for 5 hr at 1250°C in an Argonne vacuum furnace. In C_{11}, the field now rose up to 2.7 MV/m, with a much large Q_o of 1.6×10^8.

C_{12} was oxypolished and left bare in order to evaluate the oxide's contribution to the surface resistance and electron emission. Virgin Q_{oo} was 9.4×10^9, six times better than in C_{11}, the anodized helix. With a geometrical factor of 4.6, which was experimentally determined in a warm cavity, this gave a surface resistance of 4.9×10^{-10}ohm. Improved results were also obtained for the maximum accelerating field, which went up to 3.7 MV/m with a Q_o of 7×10^7.

III. MAXIMUM FIELDS

In Fig. 2, we see the excellent performance of C_{17}, a bare can which has been room temperature cycled. It is somewhat typical of uncontaminated bare C cans.

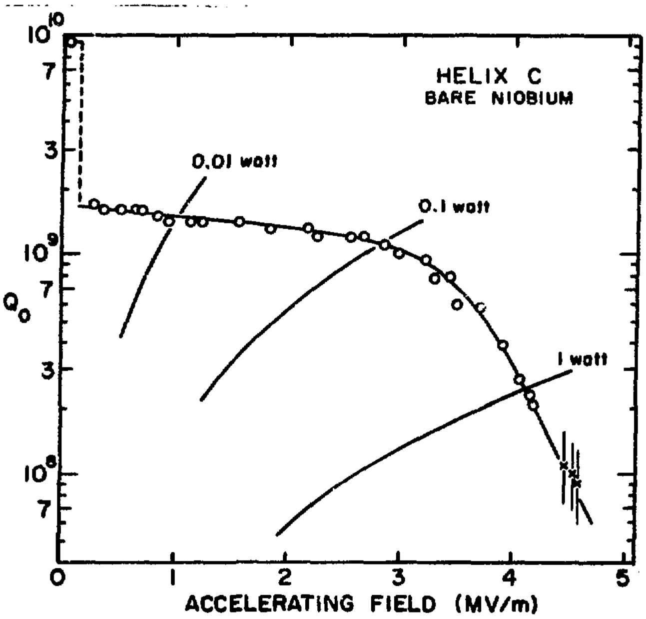

Fig. 2. Typical performance of uncontaminated bare (not anodized) C cans.

Except at very low fields where multipactoring is often encountered, surface resistance is dominant in determining Q_o up to the shoulder of the curve. Beyond the shoulder, electron emission[6] plays the major role in producing the steep descent. It is associated with x-rays and responsible for the final thermal breakdown of the cavity due to excessive power dissipation. The sustained E_{ax} (max) for this cavity was 4.4 MV/m at a Q_o of 2.4×10^8. In an on-the-fly measurement, a value of 4.6 MV/m was reached for a few sec. Theoretical calculation[7] shows that, for a resonator with the dimension of unit C, $B_{sur} = 0.07 \sqrt{PQ_o}$ and $E_{sur} = 8\ E_{ax}$, which implies that the surface magnetic field was 1200 G and the surface electric field was 37 MV/m.

IV. RF CONDITIONING

When many units are first subjected to RF power, they do not have low level multipactoring barriers, but a barrier is often present after the field's first collapse. This low-level barrier can be processed away by maintaining the RF field in the structure, a process we call RF conditioning. This process takes between one and eight hours during which one can follow the gradual rise in the field level accompanied sometimes by abrupt jumps in field. RF conditioning has the side effect of reducing Q_{oo}, by at least a factor of 2. Once through the low-level barriers and after the field reaches intermediate values, breakdowns are sometimes experienced (mostly with air-exposed cavities) with a modest power input. These breakdowns are characterized as being magnetic-thermal and are distinguished by their very short duration, of the order of a μsec. However, soon after the application of additional RF power, the field is usually extended.

V. HELIUM CONDITIONING

It has been found extremely useful to subject the cavity to a helium-ion sputter processing[8] which we label helium conditioning. It consists of introducing helium gas into the cavity while a high RF field is maintained. As the gas pressure is increased, in a successful helium conditioning, it is accompanied by an increase in field which can be maintained and exceeded even after the helium is pumped out. Fig. 3 is a good example of the gains achieved, from 0.8 to 3.7 MV/m, after 15 helium conditionings on C_{12}.

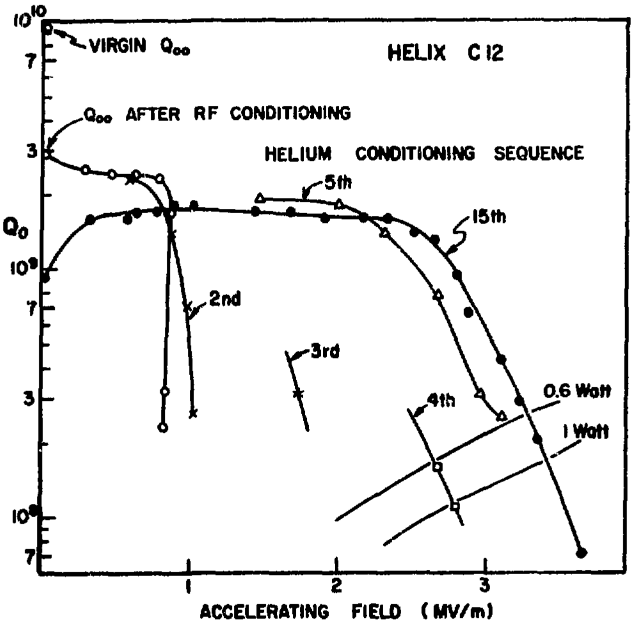

Fig. 3. Progress achieved on Helix C_{12} after a series of helium conditionings.

The conditioning is carried to the point where helium gas limits the max field and eventually reduces it to near zero. One is not certain at what helium gas pressure the max benefits of helium conditioning are obtained. In one instance a cavity was left conditioning overnight with a given amount of helium and no pumping. The other end of the time spectrum for a beneficial conditioning could be five min. Often this process has to be followed by the application of RF fields at a power level below the breakdown point of the cavity. Progress may be registered in anywhere between ten minutes to two hours after pumping is initiated. The recipe is broad because the defects one is trying to correct must be wide ranging in nature and location. In cases where magnetic thermal breakdown is not the field limiting obstacle, progress is observed as a Q_o increase for the same field, associated with a decrease in x-rays, allowing a gain in E_{ax}. Helium conditioning has the tendency to reduce Q_o at low fields and to raise the shoulder of the Q_o-E_{ax} curve and to extend its range of attainable field.

VI. AIR EXPOSURE OF BARE SURFACES

In order to determine the consequences of a vacuum failure in a real linac, unfiltered lab air was introduced into several cavities at room temperature and atmospheric pressure after having been subjected to high RF fields. The subsequent performance is compared in Fig. 4 with a bare cavity which was not exposed to air. The max E_{ax} was reduced from 4.3 to 3.1 MV/m. There was no further change in performance when the initial 2 hr exposure to air was followed by another exposure of 30 hr with RF testing between the two exposures. Hence, once deteriorated, the surface becomes immune to further deterioration.

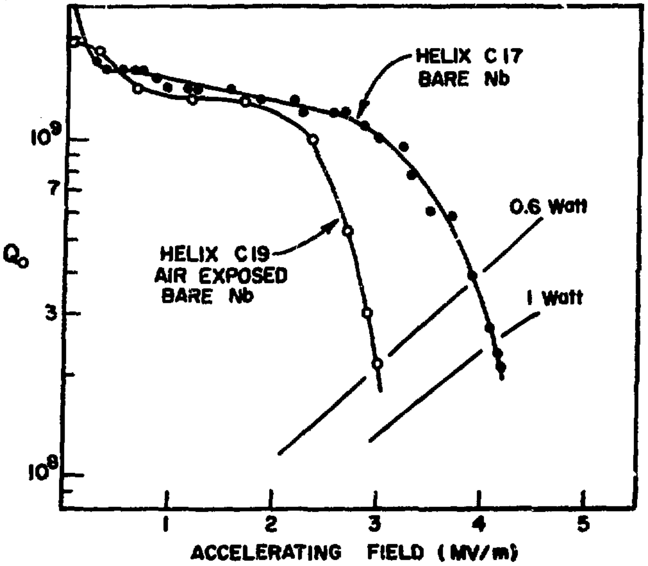

Fig. 4. Contract in performance of C_{17}, a bare cavity, to that of air-exposed C_{19}.

Following the first series of tests on the influence of air contamination[9], the same unit was taken to the lab, anodized and oxypolished. It then performed just as well as initially, producing the same peak fields and high Q's that it had achieved previous to air exposure. The air exposure was repeated once again, and it too produced the same degree of deterioration.

VII. ANODIZED SURFACES

The performance of bare and anodized surfaces are compared in Fig. 5. The fresh bare surface is seem to be substantially better, whereas the maximum field is approximately the same for the anodized and the air-exposed bare surface.

The air-exposure test was now tried with an anodized cavity, C_{21}. No deterioration in the maximum E_{ax} was observed, but Q_0 had gone down by a factor of 6. Could it be that dust was being pushed into the resonator when air was introduced? Filtered air was then tried. The bare cavity results were duplicated but this time there was no deterioration in either the field or the Q_0 of the anodized cavity, which corroborates our previous conclusion[10] on the stability of air-exposed anodized cavities. That is, it seems likely that C_{21} was exposed to dust when air was admitted.

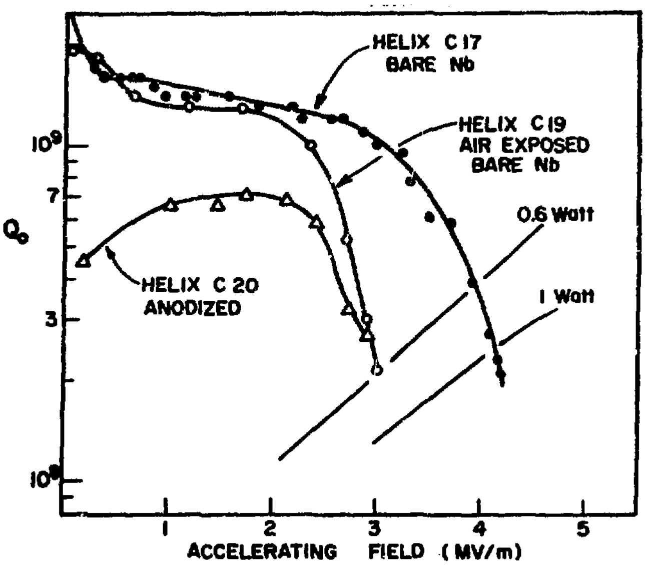

Fig. 5. Performances of C_{17}, a bare cavity; C_{19} after it is air-exposed; and C_{20}, an anodized cavity.

VIII. HEAT TREATMENT WITHOUT FURTHER SURFACE TREATMENT

C_{31} was transferred directly from furnace to pump-out lines without receiving any further treatment. It distinguished itself mainly by not having a multipactoring barrier and not acquiring one over the course of running nor even after being room-temperature cycled. It had a relatively high Q_{00} of 3.7×10^9 but, in all other respects, it performed poorly. It attained a max E_{ax} of 2.2 MV/m with a Q_0 of 1.4×10^7 after several helium conditionings.

CONCLUSION

Cavity C has shown a consistency of performance that had not been achieved previously. The techniques of treating and assembling a cavity have been so perfected that, with one or two exceptions in two dozen treatments, a given field and quality factor could be expected from a particular surface treatment. Bare Nb surfaces have repeatedly produced exceptional performances: a Q_{00} of 9×10^9, corresponding to a surface resistance $R = 5 \times 10^{-13}$ ohms, and a maximum accelerating field $E_{ax} = 4.6$ MV/m, corresponding to the surface fields $E_{sur} = 37$ MV/m and a $B_{sur} = 1200$ G.

Bare surfaces do deteriorate when exposed to air after RF had been applied to them previously. They do not deteriorate with further exposures to air. Anodized helical cavities do have stable surfaces but our results for Helix C suggest that this is because they have already deteriorated. Since bare surfaces, even after exposure to air, show a superior performance when compared to anodized cavities, they should be seriously considered for use in helical cavities. And finally, it is necessary to heat treat a cavity after the completion of all electron beam welding; clean room assembly procedures should be strictly adhered to in order to prevent dust contamination.

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REFERENCES

1. Peter H. Ceperly, HEPL Report No. 655 August 1971.

2. J. E. Vetter, B. Piosczyk, J. L. Fricke, Proc. of the 1972 Proton Linear Accelerator Conf., (Los Alamos, 1972) p. 145.

3. B. Piosczyk, Institut für Experimentelle Kernphysik KFK 1991, April 1974.

4. R. Benaroya, A. H. Jaffey, K. Johnson, T. K. Khoe, J. J. Livingood, J. M. Nixon, G. W. Parker, W. J.Ramler, J. Aron, K.E.Gray, W.A. Wesolowski. 1972 Proton Linear Accelerator Conf. (Los Alamos 1972).

5. J. Aron, R. Benaroya, L.M.Bollinger, B. E. Clifft, O. Despe, A. H. Jaffey, K. W. Johnson, T. K. Khoe, J. J. Livingood, P. J. Markovich, J. M. Nixon, G. W. Parker, W. A. Wesolowski. Proc. 9th Int'l Conf. on High Energy Accelerators, May 1974, Stanford, Calif.

6. J. Halbritter, Institut für Experimentelle Kernphysik 73-20-LIN October 1973.

7. Tat Khoe, Private Communication.

8. H. A. Schwettman, J. P. Turneaure and R. F. Waites, J. Appl. Phys. 45, 914 (1974).

9. J. A. Yasaitis, J. Halbritter, this Conf.

10. R. Benaroya, A. H. Jaffey, K. Johnson, T. KHoe, J. M. Nixon, G. W. Parker, W. J. Ramler, J. Aron, W. A. Wesolowski. Appl. Phys. Lett. Vol 21, 235, (1972).