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PERFORMANCE OF A SUPERCONDUCTING ACCELERATOR STRUCTURE WITH A MODIFIED GEOMETRY*

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Summary

A 2.4 m long superconducting niobium 1300 MHz disk loaded accelerator structure whose cell geometry was modified to reduce its sensitivity to one-point multipacting was constructed and tested. The structure has a maximum cw energy gradient for electrons of 2.3 MeV/m and an unloaded Q of 9×10^8 at this field, both of which are satisfactory. The structure appears to be less sensitive to one-point multipacting; however, this result is not conclusive because of a small helium leak in the structure. We have also found that structures which undergo large multipactor frequency shifts can be operated successfully in a pulsed-off mode.

Electron multipacting has been the most persistent problem in the operation of the 1300 MHz superconducting niobium structures for the Stanford Superconducting Recyclotron. Electron multipacting in superconducting structures results in three phenomena which affect their performance adversely in important ways. First, the reactive component of the multipactor electron current results in structures having frequency shifts which are sometimes large compared to their loaded bandwidths. This leads to the inability to keep all structures in the accelerator in synchronism while maintaining large regulated field amplitudes in those structures. Second, the multipactor current can lead to regenerative excitation of modes (multipactor excited modes) other than the operating mode. These multipactor excited modes can, under some circumstances, lead to modulation of the electron beam energy which significantly degrades the beam energy resolution. Third, intense multipacting can lead to thermal breakdown in structures. Since degradation of the structure surface can lead to increased multipacting, a structure can in time be limited by multipactor induced thermal breakdown of increasing multipactor order (decreasing field).

We have been able to demonstrate that an important form of multipacting in our structures is one-point multipacting at the outer wall of the structure cells where the outer wall begins to curve into a disk with some radius r_o.[1] The sensitivity of a structure cell to multipacting of this type decreases as the radius r_o decreases. The sensitivity to multipacting also depends on the disk taper and the diameter of the central iris. Multipactor simulation using our computer program and experimentation demonstrated that the one-point multipacting could be largely eliminated for energy gradients below 2.5 MeV/m in structure with a modified cell geometry.[1]

A 2.4 m long superconducting niobium 1300 MHz accelerator structure with modified cell geometry has been constructed and tested. The design of this structure was similar to previous structures in all respects except that the cell geometry was modified. This structure, called MS3-1, has a radius $r_o = 3.7$ mm and a disk taper of 2.9°, while structures produced before 1977 have a radius $r_o = 24.1$ mm and a disk taper of 5.7°. MS3-1 was fabricated, processed and assembled using the same methods used for the previous structures. It has been tested three times and has a maximum cw energy gradient of 2.3 MeV/m and an unloaded Q of 9×10^8 at this field both of which are satisfactory. The multipacting behavior of this structure is discussed below. The full understanding of its multipacting behavior is incomplete, however, since at the end of the last test a very small helium leak less than 10^{-6} std cm^3/s was discovered in its rf input assembly.

The electron multipacting behavior of MS3-1 was studied by measuring the frequency shift, added power loss and stray electrons produced by the multipacting. The observed frequency shift Δf and the added power loss ΔP are particularly valuable for characterization of multipacting since from them the ratio, r, of the reactive to resistive components of the multipactor current can be calculated:[2]

$$r = 4\pi U \frac{\Delta f}{\Delta P} ,$$

where U is the structure stored energy. The observation of stray electrons collected on a probe was used to confirm the presence of multipacting. The presence of multipactor excited modes also gives indirect evidence of the presence of multipacting.

A large frequency shift over a broad range of field was measured for MS3-1. These frequency shift measurements are shown in Fig. 1 as a function of average energy gradient. At low field the resonant frequency is essentially constant with increasing field until the energy gradient becomes about 0.75 MeV/m at which point the frequency shifts upwards discontinuosly by about 3 kHz. As the field increases further the frequency shift decreases linearly until it is again approximately zero at 2.2 MeV/m. If the field is then decreased, the curve is retraced until the discontinuity at 0.75 MeV/m is reached. As the field decreases further below 0.75 MeV/m, the frequency shift goes smoothly to zero at 0.2 MeV/m rather than discontinuosly.

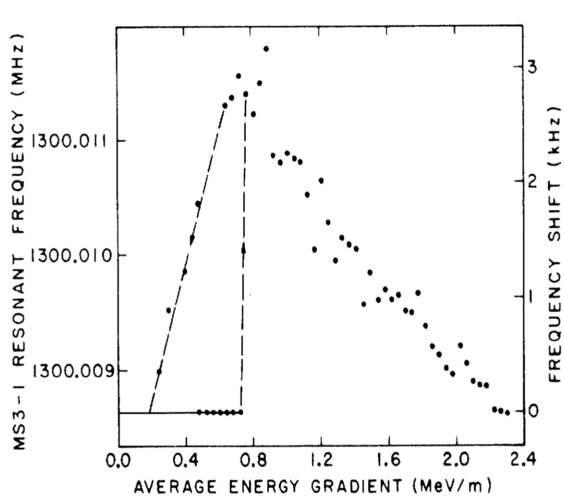

Figure 1.

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If the field is at any time turned off then on again, the resulting frequency shift corresponds to bringing the field again from zero. An important feature of the frequency shift is that it is accompanied by an undetectable amount of added power loss, less than 1 W. This leads to a very large ratio $r \geq 8 \times 10^3$ indicating that the electrons oscillate many cycles in the electromagnetic field before making resistive collisions. This large ratio is completely inconsistent with ratios expected for one-point multipacting. Multipactor simulation with our computer program shows that $r \simeq 3.8\,n$ for multipactor orders $n = 2, 3, \ldots$ Since n could be at most 11 for a field of 0.75 MeV/m, r would be approximately 42, which is 1/200 th of the measured value. The conclusion is that the broad frequency shift shown in Fig. 1 is not due to one-point multipacting at the outer wall of the type discussed previously.[1]

Observation of the broad frequency shift has not been limited to the structure MS3-1. It has in fact been observed in several of the structures. For example, for the structure 6m-4, which has been in operation for many years, the broad frequency shift has been present in some tests and absent in others. We now have some evidence, but inconclusive evidence, that the broad frequency shifts may be associated with helium in the structures. During two tests on 6m-4 made when it was isolated from other structures, the broad frequency shifts were absent. In two subsequent tests in which 6m-4 was directly connected to MS3-1 the broad frequency shifts occurred in 6m-4 as well as MS3-1. At the end of this second set of tests, a small helium leak of less than 10^{-6} std cm^3/s was discovered in the rf input of MS3-1. The beam line pressure during these tests was about 10^{-7} torr and the small helium leak did not increase it noticeably. From this and other similar evidence we believe, although not conclusively, that the helium in the structure may have an important part in the electron avalanche process that produces the broad frequency shift. The leak in MS3-1 is being repaired, and the structures will be tested again in April 1979.

A transient frequency shift over a narrow range was observed for MS3-1 during processing of that structure in January 1979. The frequency shift and accompanying power absorption are shown in Fig. 2. The data in Fig. 2 are somewhat difficult to interpret since the frequency is measured in about 1s while the available refrigeration power (negative of power absorption) represents an integration over about 100 s. The power data were observed every minute along with the frequency data (some frequency data points are missing, but the extrema are included). From the figure we can conclude that $\Delta f \leq 600$ Hz and $\Delta p \geq 40$ W, and thus that $r \leq 270$. This value is larger than but consistent with the value of 15., which was computed for 4th order multipacting (~ 2.0 MeV/m) using the multipactor simulation program. This 4th order multipacting level quickly processed to an unobservable level. No other clear evidence of one-point multipacting was observed. From the observations of MS3-1, it is clear that one-point multipacting does not lead to important frequency shifts which cause operational problems. It is not clear, except at the highest fields (2.1 - 2.3 MeV/m) if one-point multipacting leads to multipactor excited modes which will cause beam energy modulation. Multipactor excited modes were observable under some conditions, but at lower fields it is not possible to determine if the modes were the result of one-point multipacting or the broad frequency shift phenomena.

The nature of the time dependence of the broad frequency shift of MS3-1 and the older structures has been studied for some time, and it has led to use of a "pulsed-off" mode of operation to maximize the beam duty factor of the recyclotron. If the field in a structure is turned on at time t_0 for energy gradients

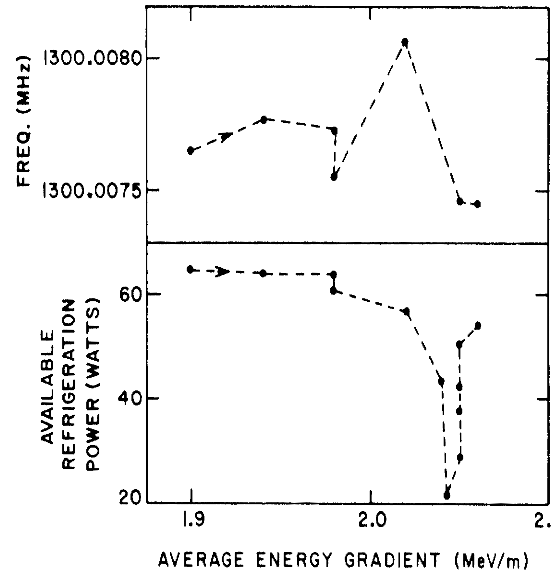

Figure 2

in the range of 1.0 to 2.10 MeV/m no significant frequency shift (< 50 Hz) takes place until $t = t_0 + \Delta t$ at which time the frequency shift begins to be observed. The time interval Δt which is free of frequency shift can vary, depending on many factors, from about 10 ms to many seconds. For some structures, there is no observed frequency shift. The important characteristic of the frequency shift time dependence is that if the field is turned off (takes about 1 ms for our structures) and subsequently turned on, the frequency shift is again delayed by Δt. Thus, a high duty factor can be achieved using a "pulsed-off" mode of operation even for structures which have large equilibrium frequency shifts. For example, if $\Delta t \geq 10$ ms for the accelerator structures it is possible to operate the structures with a pulse repetition time of 10 ms, an rf "pulse-off" time of 1 ms (rf on for 9 ms) and a beam on time of 5 ms (allows 4 ms for structure amplitudes to stabilize) which yields a beam duty factor of 50%.

Although our understanding of multipacting in MS3-1 and older structures is not complete, substantial progress has been made. First, it may be that the broad-field large frequency shift is the result of helium in the structure due to very small leaks. We have verified that such leaks have also occurred in the rf input of other structures. The leak detection system for our structures has been increased in sensitivity by about two decades, and hopefully the broad frequency shifts will not occur in the leak tight structures. Second, it appears that progress has been made in reducing one-point multipacting in the modified structure. Finally, the "pulsed-off" mode of operation allows structures to be successfully operated at high duty factor even when they have large equlibrium frequency shifts.

References

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