Operating experience with $\beta = 0.16c$ superconducting resonators

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Abstract

I. INTRODUCTION

A niobium split-ring superconducting resonator with an optimum particle velocity of $\beta = 0.16c$, was developed at Argonne for use in the ATLAS accelerator. There are two versions being used in ATLAS, the $S$ type resonator$^1$ and the $V$ type resonator,$^2$ shown in Fig. 1. Both types operate at 145.5 MHz and have a useful particle velocity from $\beta = 0.1c$ to $\beta = 0.23c$.

The ATLAS extension of the Argonne heavy-ion booster accelerator consists of three cryostat sections. The first cryostat contains six High Beta ($\beta = 0.1c$) resonators, a design which has been used since 1978 at Argonne.$^3$ The second cryostat has three $\beta = 0.1c$ resonators and three $\beta = 0.16c$ resonators. The third cryostat holds six of the $\beta = 0.16c$ resonators. These cryostats have been (on-line) in their accelerating position, with all systems installed and operational since February 1985.

This paper will discuss the off-line tests of the $\beta = 0.16c$ resonators, and the operating experience with
the ATLAS linac, and particularly the new resonators, during our initial shake down. It will also cover the performance of the $\beta = 0.16c$ resonators.

II. OFF LINE TESTS

A total of ten $\beta = 0.16c$ resonators were constructed. Testing on the initial S type took place in March 1984. During the Spring and Summer, construction of the V type resonators was being completed. In August the off-line test of the first V resonator was performed and by October off-line tests of all of the $\beta = 0.16c$ resonators were complete.

One of the main objectives of the off-line tests is to evaluate the performance of each resonator. Any defects in the resonator construction would be detected, also the accelerating field vs. power into the He bath will be determined during an off-line test. A graph of the quality factor vs. field level gives us that information at a glance. There is a variable coupled rf drive probe in the test cryostat that allows for the direct measurement of both the rf power in and the critically coupled decay time of the resonator. With this information one can calculate the field level and the quality factor.

Upon being cooled down from room temperature to 4.5°K the resonators exhibit heavy electron loading due to multipactoring barriers (MP) which limit the
accelerating field level. The multipacting behavior in the $\beta = 0.16c$ resonators is different from the earlier split-ring resonator design in that a MP barrier at $ea \sim 0.1 \text{ MV/m}$ does not condition away with the continued application of rf power at 144.5 MHz.\textsuperscript{1} This MP level is strongly coupled to a 134 MHz mode in which the drift-tube voltages are symmetric rather than antisymmetric as in the 145.5 MHz accelerating mode.

To condition away this MP barrier the rf Power must be applied in the 134 MHz Mode. Once this barrier is gone conditioning at the 145.5 MHz mode may be done. After all of the MP conditioning is finished there is still a weak, persistent, mode mixing barrier at $ea \sim 0.6 \text{ MV/m}$. Although this barrier does not go away, it is not an operational problem. It is not a strong barrier and the control module can easily bring the field level on and past that level.

High level He gas pulse conditioning is done in the same manner as for the lower $\beta$ split-ring resonators.\textsuperscript{2} This pulse conditioning helps to further reduce electron loading at higher field levels.

Figure 2 shows a typical result of an off-line test. This graph illustrates the reduction of electron loading after He conditioning. The average of all of the off-line tests done on the $\beta = 016.c$ resonators is an accelerating field of 3.7 $\text{MV/m}$ at 4 watts of power.
into the He bath. At 8 watts of power into the He bath the average field level is 4.3 MV/m.

III. ON-LINE EXPERIENCE

The measurement of the Q of an on-line resonator is less direct than in off-line tests. There are two systems present on-line that prevent using the same Q measurement technique as off-line. First, the coupling of the rf drive probe is fixed, so it is not always critically coupled. Second, there is a fast tuning system (VCX) at 77°K, which is mounted on the resonator. The VCX system absorbs ~95% of the rf power put into the resonator and dissipates it into the LN$_2$ rather than the Helium bath. The overall Q is therefore a factor of 20 or more lower than for a bare resonator and a direct Q measurement is not useful.

In off-line tests we have noticed that at the high field levels of interest where electron loading occurs, ~50% of the rf loss occurs via electron impact into the resonator housing. Since the housing cools by conduction, the rf loss generates heat and a consequent temperature gradient. On-line there is mounted on each resonator a pair of resistive heaters and a germanium resistance thermometer. By applying a known power to the heaters, one can very accurately measure the temperature gradient per unit in the resonator housing heat load. With this calibration the rf loss into the
housing is determined, and a good estimate can be made of the total rf power into the resonator. It is then possible to calculate the Q of the resonator at a given field level. Figure 2 shows such an on-line Q curve.

The on-line MP conditioning is the same as off-line. The process on-line takes approximately 4 hrs. per resonator. When MP conditioning on-line, usually four or five resonators can be done at one time. There seems to be very little occurrence of MP barriers on-line once the resonators are operating. Occasionally MP will re-establish in some of the resonators in the first week or two after cool down, but these re-occurring barriers easily condition away with 5-10 minutes of work. After the first one or two weeks, MP barriers almost never re-occur.

In March of 1985, all of the ATLAS cryostats were cooled down to 4.2°K and the MP barriers were conditioned away. High-power pulse conditioning was done for a very brief time and moderately high field levels were achieved. In May, the refrigerator was shut down for four months. Over this entire time period two of the ATLAS cryostats were kept at temperatures in the range of 77-126°K. Upon cooling down to 4.2°K in September, the resonators in these cryostats exhibited very little MP. Only a few minutes of conditioning was required to remove MP barriers, and
the field levels reached in March were re-achieved with no high-power pulse conditioning.

Q curves have been taken for all of the $\beta = 0.16c$, resonators on-line. Table 1 shows the field level with 4 watts of rf input power after conditioning. The resonators are not limited to operating at 4 watts in, and can in fact be operated with 7 or 8 watts of rf input. The operating level of all the resonators depends on the total refrigeration available.

The mechanical stability of the $\beta = 0.16$ resonators in on-line operation is very good. The mechanical vibration induced eigenfrequency jitter is approximately 9 to 15 Hz p-p and is down by a factor of about 3-1/2 from the other split-ring designs. This is a result of the shorter, more rigid construction of the loading arms.

IV. CONCLUSION

Although MP conditioning takes about 4 hours for an individual resonator, conditioning several resonators at one time is straightforward, and the entire accelerator can be conditioned in two days. Also, re-occurring MP barriers have not been found to be a serious problem.

Although on-line performance is entirely acceptable, it does not yet match off-line test results.
as is shown in the curves in Fig. 2. Efforts continue to resolve this difference.

We have found that resonators can be warmed to at least 126°K for several months without recurrence of MP. This has been a fortunate result, since refrigeration failure for even extended periods of time does not necessarily cause deconditioning of the linac.

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Figure Captions

Fig. 1  A view of a "V" type $\beta = 0.16c$ resonator.

Fig. 2  An off-line Q curve, both before and after He pulse conditioning, and a Q curve of the same resonator on-line.
<table>
<thead>
<tr>
<th>Resonator</th>
<th>Field Level</th>
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<tr>
<td>$S_1$</td>
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</tr>
<tr>
<td>$S_2$</td>
<td>3.92 MV/m</td>
</tr>
<tr>
<td>$S_3$</td>
<td>3.2 MV/m</td>
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<td>2.7 MV/m</td>
</tr>
<tr>
<td>$V_7$</td>
<td>3.1 MV/m</td>
</tr>
</tbody>
</table>

**TABLE 1: Operating Field Levels at 4 Watts of rf power into the He bath for all of the $\beta = 0.16c$ resonators which are installed in ATLAS.**
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TEST CRYO. AFTER He CONDITIONING

ON LINE PERFORMANCE

TEST CRYO. BEFORE He CONDITIONING

4 watts rf IN

8 watts rf IN

$E_a$ (MV/m)

$Q$