SUPERCONDUCTING RF SYSTEM OPTIONS FOR DIAMOND

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Abstract

The proposed UK Light Source DIAMOND has an operating energy of 3 GeV, with a current of 300 mA. With the full complement of insertion devices the energy loss per turn is greater than 2.25 MeV, and the required RF energy acceptance is greater than 3 %, consequently an accelerating voltage of 5.1 MV is needed. Investigations using a warm cavity system for DIAMOND have been reported elsewhere [1], this paper discusses the advantages of using a superconducting RF system, and outlines a possible system arrangement that fulfils the requirements.

1 INTRODUCTION

During the feasibility study for the proposed UK Light Source DIAMOND, the reference RF system design was based on normal conducting (or warm) technology. This paper briefly reviews this reference design, and suggests possible alternatives using superconducting technology. Table 1 below summarises the basic DIAMOND parameters used to design this reference system.

Beam Energy	3	GeV
Beam Current	300	mA
Magnet Bending Radius	7.128	m
No Multipole Wiggler Magnets	9	
No of Superconducting Dipoles	4	
Momentum Compaction	0.000849	
RF Acceptance	3	%
Energy Loss per Turn	2.25	MeV
Overvoltage	2.35	
Beam Power	653	kW
Required Peak Voltage	5.1	MV

Table 1. DIAMOND Parameters.

2 REFERENCE DESIGN

Assuming an effective shunt impedance of 4 MΩ per cavity, (taking into account the various losses due to beam ports, tuner port, coupling port and changes in the material conductance due to high power loading, etc.), six normal conducting cavities are used. As can be seen from figure 1 there are 3 cavities located in two straights, and there is one klystron feeding each cavity. An RF power of 540 kW is required to produce the accelerating voltage.

The reference 500 MHz cavity [2] has 109 higher order modes (HOM's) below the beam tube cut off, and with the full complement of insertion devices (increasing the radiation damping), 52 of these modes are potentially unstable.

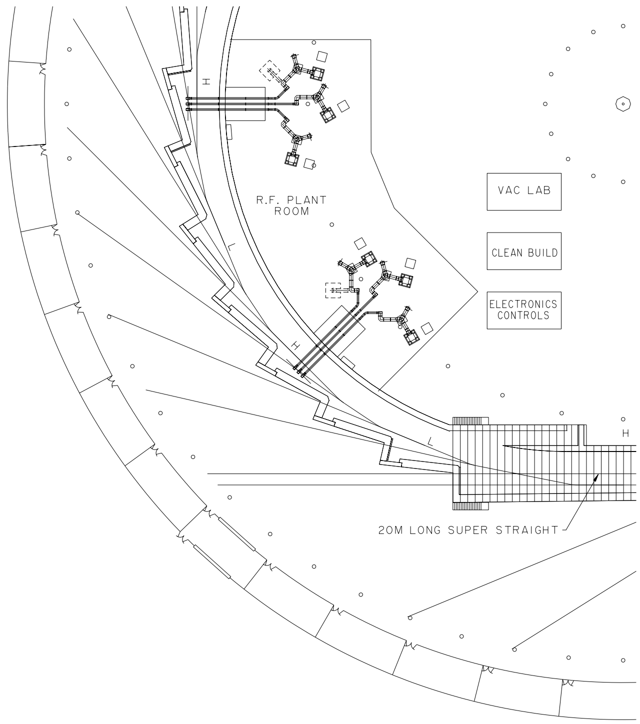

Figure 1. Layout of DIAMOND Storage Ring showing RF System Configuration.

HOM's can be eliminated or suppressed in a number of ways: during the design stage damping waveguides can be added to the cavity - this along with longitudinal and transverse beam feedback is being used at the SLAC B Factory [3]. At Elettra [4] the modes are avoided by the use of accurate temperature control of the cavity and fixed HOM phase shifters in the cavity – but this is only effective with a small number of modes and a large orbit frequency. Other methods would include harmonic separation of one or more cavities, using gapped beam to increase Landau damping or damping wigglers. The latter would of course increase the required RF power.

3 SUPERCONDUCTING RF SYSTEM

Until recently superconducting RF systems for light sources have rarely been considered. They were regarded as too complex and costly, however the use of a superconducting system gives the ability to damp all the monopole modes and the significant dipole modes. With the development of superconducting RF for other accelerators the capital costs for both warm and

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superconducting systems have become comparable. The performance already achieved at Cornell [5] is that required for DIAMOND. Recent CERN experience has shown that the fault time with superconducting systems is no greater than equivalent warm systems.

Using the same parameters as in table 1 above, but now assuming an effective shunt impedance of 4000 MΩ, only 3 superconducting cavities, with a much simpler geometry (with an R/Q of 40, say) are required. The number of possible HOM's is drastically reduced, and they can be damped, either with ferrite dampers in the beam tube [5] or with HOM couplers as at CERN. Table 2 compares the RF parameters for both options.

	'WARM'	'COLD'
Beam Power	653 kW	653 kW
Cavity Power	541 kW	86 W
No. Cavities	6	3
Window Power	199 kW	217 kW
No. Klystrons	6	3
Klystron Power	250 kW	250 kW
Total RF Power	1314 kW	718 kW

Table 2. Comparison of RF Parameters for Warm and Cold Systems.

As can be seen the total RF power needed for the superconducting case is approximately half that required for the normal case. Also the number of RF systems is halved, however two straights of the ring are still required. Figure 2 is a representation of a possible 350 MHz superconducting cavity, based on the CERN design for LHC, and figure 3 shows the proposed DIAMOND layout.

There are , of course, disadvantages as well:

1. The enormous beam power compared to the cavity power results in the necessity to provide complex feedback systems to prevent system instability.
2. The development of superconducting RF systems for a relatively low number of cavities, particularly if the Laboratory has no relevant expertise, is expensive.
3. The recovery time from a cryogenic incident can be long.

4 HYBRID RF SYSTEM

A third option is to use a combination of normal conducting cavities to provide the beam power and accelerating voltage, then to use an idle superconducting system to provide the required overvoltage. Such a system was proposed by Marchand for the CERN/PSI B-factory project [6] and more recently to improve the energy acceptance in the SLS storage ring [7].

For DIAMOND the beam power and acceleration voltage could be supplied by 3 normal conducting cavities with a low number of HOM's, which could be controlled by temperature compensation, and then use two idle superconducting cavities to provide the potential well to give a longer beam lifetime and the associated energy acceptance.

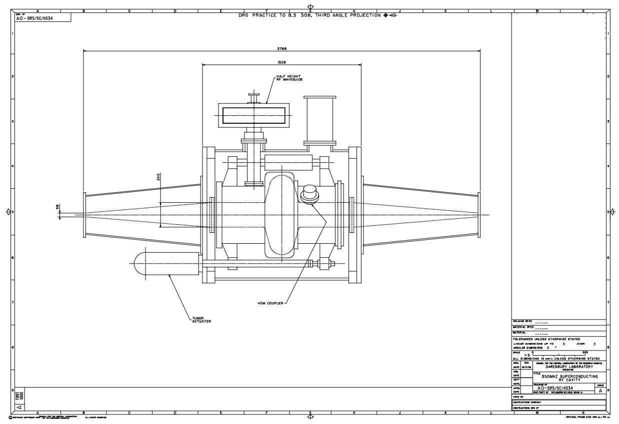

Figure 2. 350 MHz Superconducting Cavity in Cryostat

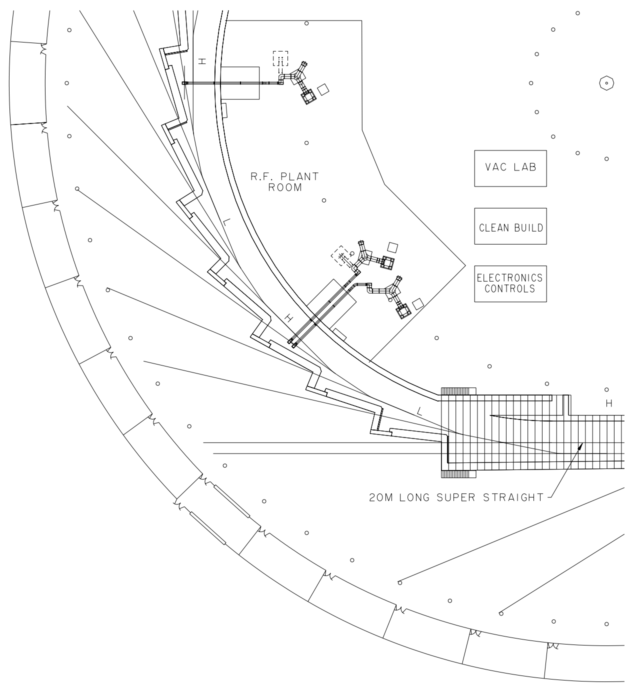

Figure 3. Layout of DIAMOND Storage Ring showing Superconducting Cavity Option.

As derived by Marchand [7] when a cavity is detuned far from resonance ($\delta f >> fr/Q$), the voltage induced by the beam passing through is given by:

$$V \sim Ib\ (R/Q)\ fr/\delta f$$

Where V is the induced voltage in the idle cavity
Ib is the beam current
fr is the RF frequency
δf is detuned frequency
and Q is the cavity quality factor

As this formula shows, the induced RF voltage can be controlled by frequency tuning the cavity. For a superconducting cavity the Q is very high ($\sim 10^9$), and the R/Q is typically 40 Ω, so an induced voltage of 1.5 MV is easily achievable. The power lost by the beam as it passes through the cavity is less than 300 watts.

The RF parameters for a hybrid system for DIAMOND are given in table 3.

Beam Current	300	mA
Energy Loss per Turn	2.25	MeV
No 'Warm' Cavities	3	
No 'Cold' Cavities	2	
Peak Voltage	5.35	MV
Energy Acceptance	3.2	%
Beam Power	654	kW
'Warm' Cavity Power	230	kW
'Cold' Cavity Power	570	W
Total RF Power	970	kW

Table 3. RF Parameters for DIAMOND Using a Hybrid RF System.

The hybrid system has the advantage of using normal conducting cavities, which have fewer HOM's than the case for the reference design, and then uses superconducting cavities with no external feed, where the HOM's will be suppressed using couplers in the beam pipe.

The superconducting cavity system will be relatively simple, as there is no external feed. The cavity will consist of the basic cavity, with a tuning system, in a cryostat: no input couplers.

5 SUMMARY

There are 3 possible options for the DIAMOND RF system:

1. Normal conducting cavities: would require 6 cavities each with 52 potentially dangerous HOM's. The total RF power required is 1314 kW.
2. Superconducting cavities: would require 3 cavities, modes could be damped using HOM couplers. Daresbury has no superconducting RF experience. The total RF power required is 718 kW.
3. Hybrid system: Requires 3 normal conducting cavities, with few HOM's and 2 superconducting cavities with no external feed. The total RF power required is 970 kW.

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