SUPERCONDUCTING RF SYSTEMS FOR LIGHT SOURCES?

D.M.Dykes, P.A.McIntosh, M.W.Poole and V.P.Suller
CLRC Daresbury Laboratory, Warrington WA4 4AD, Cheshire, U.K.

Abstract

Advanced Synchrotron Light Sources must perform with extremely high beam stability to maintain their source brightness characteristics, and this must be achieved with large multi-bunch beam currents. With the provision of very low emittance and use of high harmonic output from insertion devices, control of beam current instability thresholds is essential. At present no operating Light Source uses superconducting technology for its main RF system, although several such proposals are now being made and have been discussed at a recent international Workshop on this topic. The paper reports on the potential effect of a superconducting RF solution on these thresholds, together with the technical and economic realisation, operating reliability and efficiency, with particular emphasis on the UK DIAMOND project. Reference is made to the Workshop conclusions.

1 WHY SRF?

Superconducting RF (SRF) systems exhibit several advantages compared with room temperature systems. Because the surface resistivity of SRF structures is extremely low the dissipated power in the structure is low and higher accelerating voltages can be more easily produced. This gives the designer the option of using less efficient designs which exhibit lower Higher Order Modes (HOM) and easier methods of damping them. Both the smaller number of required cavities and their better damped HOMs lead to increased thresholds for beam instabilities.

It is also apparent that SRF systems have an overall lower energy consumption, even taking into account that consumed by the cryogenic plant, so that an equivalent room temperature system would be more costly to both purchase and operate.

2 APPLICABLE SRF EXAMPLES

Although no light source currently uses SRF the existing Taiwan light source SRRC [1] and the Canadian light source project [2] both intend to install SRF systems. These will be procured from industry and will be manufactured to the CESR design under licence. The SOLEIL project also proposes to use SRF.

The CESR storage ring at Cornell University [3] utilises four solid niobium 500 MHz single cell accelerating cavities as shown in Fig. 1.

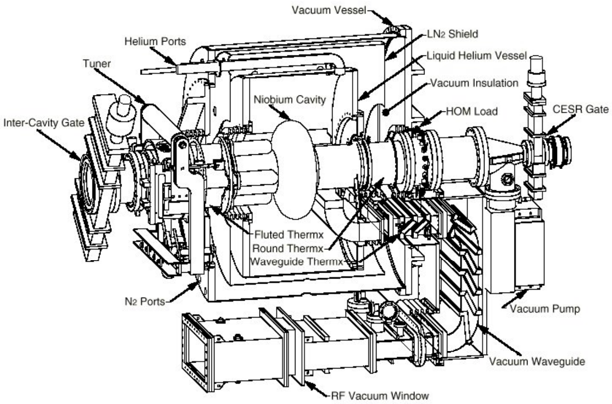

Figure 1: CESR Cavity Layout

With this particular design the CESR cavity HOM impedances that can be driven by the beam have been minimised. The HOMs propagate from the cavity via the large beam ports, and are then captured in the beam pipe at room temperature by absorbing material inserts. Since the initial installation in 1997, the RF power transferred to the beam has steadily increased. It is the intention to eventually deliver 325 kW per cavity to the beam to allow beam currents of 1 Ampere to be stored.

The cavity system developed at KEK [4] for the asymmetric B-factory High Energy Ring (KEK-B) is a 508.8 MHz, solid niobium single-cell structure (see Fig. 2). The HOMs for this design are extracted in a similar way to the CESR cavity. It utilises a coaxial input coupler that is capable of delivering 380 kW to the beam.

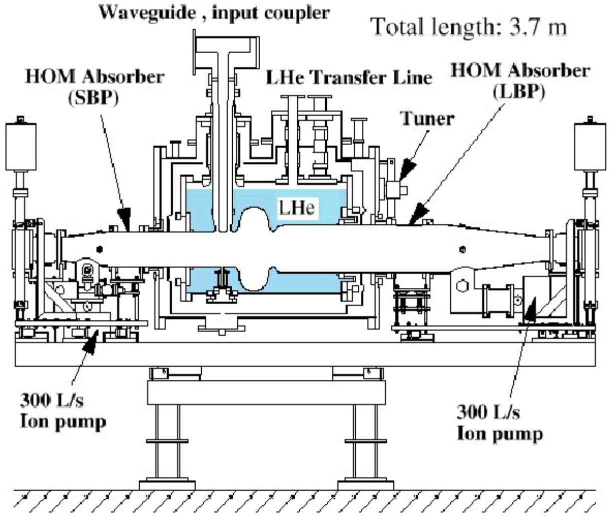

Figure 2: KEK-B Cavity in Cryostat

The technique of sputter-spraying niobium onto copper has been developed at CERN for the LEP-II upgrade cavities. This provides increased stability against thermal breakdown due to the higher thermal conductivity of copper. The same technology has been employed for the 400 MHz LHC cavities [5] (see Fig. 3).

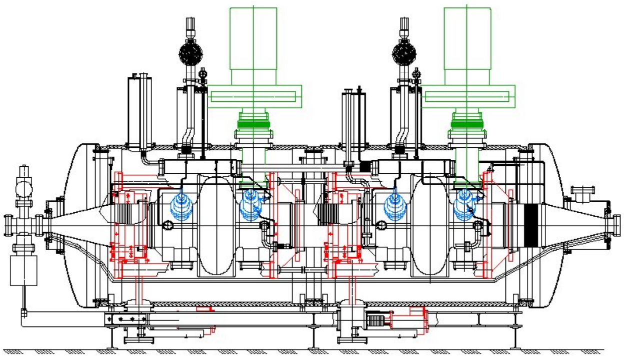

Figure 3: Two LHC Cavities Assembled in Cryostat

The cavity HOMs for this design are extracted via loop antennas located close to the cavity itself, in the large beam tubes at cryogenic temperatures.

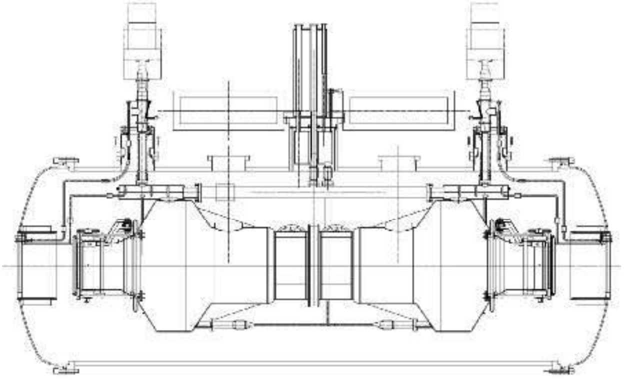

Figure 4: Two SOLEIL Cavities assembled in Cryostat

The SOLEIL [6] cavity prototype has adopted the CERN experience with Nb/Cu cavities. The single cryostat houses two 352 MHz single-cell structures (see Fig. 4) and is powered through 2 LEP type input couplers, capable of delivering 220 kW of RF power per coupler to the beam.

3 WORKSHOP

In April 2000 an international workshop was organised in Chester, UK by the Daresbury Laboratory [7]. The aim of the workshop was to consider the performance of existing SRF systems and make recommendations on their suitability for the DIAMOND light source.

Issues which were addressed by the workshop were:-

- The avoidance of HOM driven instabilities by using SRF;
- The reliability of SRF in a light source;
- The optimum frequency;
- The economics of SRF.

The workshop concluded that increased instability thresholds had been clearly demonstrated by the use of SRF. There was no clear preference for frequency, but a 500 MHz SRF could be obtained from industry to a proven design. For a light source with no in-house experience of SRF it would be essential that a cavity and coupler design was adopted which had been proven with beam. This would ensure that the necessary reliability could be achieved for use in a light source. The economics favours SRF over room temperature systems.

4 SRF FOR DIAMOND

Taking the conclusions of the workshop into account, an SRF system for DIAMOND must be at a stage where a complete, beam proven system (cavity, input coupler, HOM dampers, cryostat and tuner) could be acquired direct from industry. A number of existing SRF systems have been considered which are either already operational in existing accelerators or else are at the prototype stage.

A suitable SRF system for DIAMOND could comprise 2 CESR type cavities, each in its own cryostat and with a CESR coupler. This would allow 300 mA at the beam energy of 3 GeV with a likely complement of insertion devices. A power of 536 kW (only ~60 W would be dissipated in the cryostat) would generate an accelerating voltage of 4 MV and this would give a momentum acceptance of 4%.

5 SYSTEM PERFORMANCE

For SRF to be viewed as a viable option for DIAMOND, the technology must show reliability in a light source at least comparable with normal conducting RF systems. The necessary cryogenic infrastructure will introduce an additional reliability consideration.

Modern 3rd generation light sources strive for beam stability and the RF system is a major source of potential instabilities. SRF cavity designs are able to use much larger beam tubes, the consequent reduction in geometric shunt impedance (R/Q) being insignificant due to the much higher Q factors achieved compared to normal conducting cavities. The major advantage is then that the impedances of the HOMs are also greatly reduced, consequently minimising the multi-bunch instabilities that can be driven in the SRF cavities.

5.1 Operational Reliability

SRF technology is not currently mainstream on synchrotron light sources, however the inherent stability advantages have meant that it is being viewed favourably either as an upgrade to existing sources (eg SRRC) or else as a fundamental design decision for new 3rd generation accelerators (eg SOLEIL and DIAMOND).

LEP-2 at CERN is the largest user of SRF cavities for a storage ring and utilises 288 Nb/Cu sputtered cavities operating at 352 MHz and an accelerating gradient of 6 MV/m, with the intention of increasing to 7.2 MV/m. It is probably the best example of operational performance statistics for SRF systems currently available.

Operationally the cavities do not suffer from E-field quench limitations, even though the accelerating gradients (E_{acc}) generated are close to the operational limits. Currently in LEP, a trip rate MTBF of ~23 days for a single SRF cavity is achieved, although this shortens significantly when higher collision energies are used. Experience at CESR and KEK-B show similar MTBF trends when the demand on the SRF system approaches the operational limits. The continuous mode operating regime of light sources differs from colliders. Therefore care must be taken, when adopting an SRF system for a facility such as DIAMOND, that the demands on the SRF cavities do not lead to unacceptably reduced reliability.

5.2 Instabilities

An assessment of the performances of several potential SRF systems for DIAMOND in terms of the estimated beam current instability thresholds is shown in Table 1.

Table 1: SRF Instability Thresholds

	CESR	KEK-B	LHC[1]	SOLEIL[2]
V /cell (MV)	2.5	2	2	2.5
Gradient (MV/m)	2.5	2	2	2.5
TM R/Q (Ω)	44.5	46.5	44	45
Length (m)	3	3.7	8	6
Max $R^{//}_{HOM}$ (Ω)	200	1000	1950	3200
Max $R^{\perp}_{HOM}$ (kΩ/m)	2.5	0.85	1.5	4.5
$I^{//}_{th}$ (Amps)	28.06	5.61	2.88	2.50
$I^{\perp}_{th}$ (Amps)	6.66	19.59	11.10	3.70

[1] Assumes 4-cells/cryostat.

[2] Assumes 2-cells/cryostat.

The instability thresholds are calculated as follows:-

$$I^{//}_{th} = \frac{2(E_o/e)\,f_s}{f_{rev}\alpha\tau_s n}\,\frac{1}{f^{//}_{HOM}R^{//}_{HOM}} \qquad (1)$$

$$I^{\perp}_{th} = \frac{2(E_o/e)}{f_{rev}\beta_{\perp}\tau_t n}\,\frac{1}{R^{\perp}_{HOM}} \qquad (2)$$

where: E_o = beam energy (eV)
f_s = synchrotron frequency (Hz)
f_{rev} = revolution frequency (Hz)
α = momentum compaction
τ_s = longitudinal damping time (s)
n = number of cavities
$\beta_{\perp}$ = beta function at the cavity (m)
τ_t = transverse damping time (x or y) (s)

$R^{//}_{HOM}$ and $R^{\perp}_{HOM}$ are the maximum longitudinal and transverse HOM impedances, and $I^{//}_{th}$ and $I^{\perp}_{th}$ are the corresponding current instability thresholds.

It is clear from Table 1 that any of the example SRF systems in DIAMOND would eliminate the possibility of HOM driven instabilities occurring at the nominal beam current.

5.3 Cryogenics

It is anticipated that a 500 W cryogenic system capacity will be required on DIAMOND. As the E_{acc} gradient required will not be excessive there are no overwhelming advantages to operating below 4.4 ^{o}K. Standard atmospheric pressure systems are well established and reliable solutions.

5 CONCLUSIONS

A light source with an SRF system will derive improved beam performance by substantially increased thresholds for HOM driven instabilities. SRF systems are also likely to be more economic to install and operate than equivalent room temperature cavities. They have demonstrated the level of reliability required for the RF system of a light source and being obtainable from industry can be a feasible option for a facility with no previous SRF experience. It is likely that a decision will be made to adopt an SRF solution for DIAMOND.

ACKNOWLEDGEMENTS

The authors would particularly like to thank D Boussard, D Proch and E Weihreter for their valuable assistance during the “SRF for Light Sources” Workshop, held in Chester on 14th – 16th April 2000. The data provided for the CESR cavity was by H Padamsee, for the KEK-B cavity by T Tajima, for the LHC cavity by D Boussard and for the SOLEIL cavity by A Mosnier.

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