THE DIAMOND LIGHT SOURCE RF SYSTEM

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Abstract

The Diamond Light Source (DLS) storage ring RF system will use single cell superconducting accelerating cavities, which are being manufactured as a turnkey contract. An overview of the whole storage ring RF system is presented, with emphasis on the choice of cavity type and the required 4.5 K cryogenic plant.

INTRODUCTION

Diamond is the UK's new 3rd generation synchrotron radiation source being built at the site of the Rutherford Appleton Laboratory in Oxfordshire. Diamond is the largest scientific research facility to be built in the UK for 30 years, and will produce ultra-violet and X-ray beams of exceptional brightness, allowing pioneering experiments to be carried out, which probe deep into the basic structure of matter and materials. The facility will comprise a 3 GeV electron storage ring, injected from a 100 MeV linac through a full energy booster synchrotron.

STORAGE RING RF SYSTEM

On day-one the Diamond Storage Ring RF system will consist of two superconducting accelerating modules. Each module will be capable of delivering up to 300 kW of RF power at 500 MHz to the beam with a peak accelerating voltage of up to 2 MV per cavity.

Each cavity will be fed via WR1800 waveguide from an amplifier. To protect the amplifier a high power circulator and water load is inserted between the cavity and the amplifier.

The 300 kW is achieved by combining the RF power from up to four broadcast type IOTs combined using a classical system of waveguide components such as coax-to-waveguide transitions, hybrid combiners and switchless combiners with reject loads.

The combining system is designed to allow combination of up to four IOTs to achieve the required RF power, but in addition it will be possible to achieve ~ 160 kW using only two IOTs when required without a significant reduction in the overall efficiency. Initially two of the Storage Ring Amplifiers will be equipped with three IOTs each and one will be equipped with two IOTs. This allows for easy upgrading to the full 300 kW later, and yet provides the required RF power for day-one operation.

The DC power to the IOTs is provided from a High Voltage Power Converter (HVPC). The HVPC is based on the Pulse Step modulator technology of Thales. 64 self-protecting modules are used resulting in a system, which does not require a separate crowbar to protect the tubes in case of an arc.

The HVPC comes with a built-in control system based on EPICS, and will control, monitor and record all RF measurements. Solid state amplifiers will be used to drive the IOTs with one amplifier per IOT.

The 300 kW ferrite circulator and water load will be manufactured by AFT.

A contract for two accelerating modules has been placed with ACCEL.

A contract for the three high power amplifiers has been placed with Thales M&B.

Calls for tenders for waveguide, low level RF and for the Cryogenic plant will be issued shortly.

It is planned to operate Diamond with up to 500 mA of beam current at a later date and the current design allows for relatively easy upgrading of the system by the installation of one additional cavity and installation of additional IOTs.

CHOICE OF CAVITY TECHNOLOGY

There are a number of advantages of using superconducting cavity technology over more conventional normal conducting cavities.

The first and most obvious is the low loss of superconducting cavities due to the low surface resistivity. This results in a much reduced RF power requirement. In addition, the low surface resistivity allows the cavities to be operated at higher accelerating voltages and fewer accelerating modules are required.

Another significant advantage of the reduced surface resistance is the very high Q_0 (> 10^8 – 10^9), typically 5 orders of magnitude greater than for more conventional normal conducting cavities. Normal conducting cavities are typically designed with a high shunt impedance which reduces the power dissipated in the cavities for a given accelerating voltage. Typically this would result in cavities with a high shunt impedance of any higher order modes, which can lead to beam instabilities. The high Q_0 and resulting low dissipation of superconducting cavities allows the cavities to be designed for a low shunt impedance for the higher order modes, increasing the threshold for beam instabilities.

Figure 1 shows a picture of a 500 MHz Cornell niobium cavity with the large round and 'fluted' beam pipes designed to prevent higher order modes being trapped in the cavity region.

Figure 1: 500 MHz Cornell cavity.

The capital cost of a cryogenic plant must be offset against the cost of additional cavities. The reduction in RF power required, is similarly off-set against the operating costs associated with maintaining the cavities at 4.5 K.

The cavities and related cryo-modules have been adapted from an original design by Cornell. This cavity now has a proven record, being produced by industry for Cornell, SRRC and the CLS.

A turn-key contract for the manufacture of the two, day-one niobium accelerating modules has been placed with ACCEL, who has gained valuable experience in this field by producing a number of these accelerating modules in recent years. Figure 2 shows a cutaway view of a superconducting cavity placed within the cryostat module.

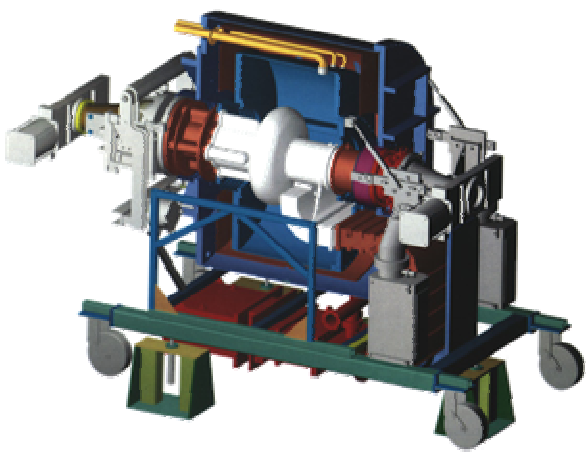

Figure 2: Cutaway view of superconducting module.

CRYOGENIC SYSTEM

The major components of Diamond's Superconducting RF 4.5K Refrigeration/Liquefaction plant system will include two main helical screw type compressor sets with related oil removal systems; one turbo expander type refrigerator/liquefier; a gaseous helium buffer storage system, capable of storing the total Helium inventory; a liquid helium dewar with a minimum capacity of 2000 litres and a liquid nitrogen distribution system. Some main components offer redundancy and the total plant will afford overcapacity.

Distribution

The Refrigeration plant will deliver cooling to a distribution valve box via evacuated multi-channel transfer lines. The distribution valve box that will be situated in an elevated position adjacent to the storage ring tunnel will then direct the cryogens to each individual cavity cryostat. All multi-channel transfer lines will be kept to an absolute minimum length for maximum thermal efficiency. Figure 3 shows a possible layout of the main components of the Refrigeration plant and their relation to the superconducting cavities.

The cryogenic plant will be capable of supplying in excess of 220 litres/hour in total to each of the cavity cryostats. Recovered cold helium gas will be routed back to the Refrigeration plant via the distribution valve box to aid the efficiency of the refrigeration/liquefaction process.

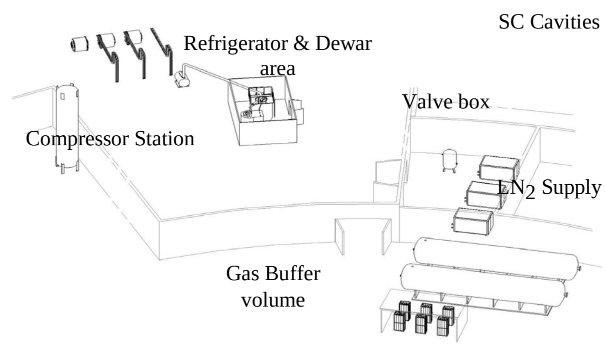

Figure 3: Schematic showing the Cryogenics layout.

Compressed helium (the refrigeration stream) is expanded through two turbo expanders in series to just over atmospheric pressure. This expansion cools the gas, which then flows through the low pressure pass of the heat exchangers to provide refrigeration. It returns to the suction of the compressor. Additional refrigeration to increase the liquefaction capacity can be provided by injecting liquid nitrogen into the first heat exchanger as a pre-coolant.The remainder of the compressed helium gas (the liquefaction stream) continues through the high-pressure pass of the heat exchangers and is cooled in the counter-flow with the refrigeration stream. An adsorber removes trace gases such as hydrogen. The gas is then expanded through the J-T valve and this further cools and partially liquefies the helium. The liquid helium then enters the liquid helium dewar, while the vapour part returns to the low pressure pass of the heat exchangers so that its cold is recovered as it returns to the compressor.