# THE CLS SRF CRYOGENIC SYSTEM UPGRADE

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*Abstract*

The Canadian Light Source currently makes use of a 500 MHz CESR-B type SRF cavity in its storage ring. While the performance of this cavity has generally been good, the reliability of the cryostat and cryogenic system has suffered a few setbacks over 10+ years of operation. The position of CLS as a user facility requires reliable beam to be consistently delivered. For this reason CLS is undertaking an upgrade project to improve system reliability and reduce downtime due to planned and unplanned maintenance. The upgrade is to include a redundant helium compressor, and new cryogenic infrastructure. In addition, the spare CESR-B cryomodule will be installed and operating in the storage ring. This paper reviews the problems with the current system to date, and discusses the proposals for the upgrade of the system.

## INTRODUCTION

The Canadian Light Source (CLS) is a third-generation synchrotron facility located in Saskatoon, Canada. CLS has been using a single 500 MHz CESR-B [1] superconducting radio-frequency (SRF) module in the storage ring for over a decade. The CESR-B module was developed at Cornell University in the 1990s, and has been licensed to various private companies for construction. CLS has two CESR-B modules, one operating and one spare.

While system reliability has not been poor, there are issues that have come up over the 10+ years of operation of the SRF system at CLS. To further improve reliability CLS is currently working on a system upgrade that would see a spare compressor added to the system and the second CESR-B unit installed in the storage ring. This will give CLS operational capabilities similar to those at NSLS-II [2] and Diamond Light Source [3].

## EXISTING SYSTEM

Figure 1 shows a schematic of the current storage ring system at CLS. This system contains one CESR-B type 500 MHz installed in straight 12 of the CLS storage ring. This SRF cavity is fed with liquid helium by a Linde TCF-50 cryoplant, consisting of a 200 kW Kaeser helium compressor, an oil removal system (ORS), a gas management panel (GMP), a coldbox, and a 2000 L Cryofab dewar. The original load specification for this plant was 284 W at 4.4 K, and the plant was tested to 313 W during commissioning.

To reduce the impact of compressor vibrations on the storage ring and beamlines, the cryoplant is located off of the experimental floor. A 52 m long multi-channel transfer line (MCTL) connects the cryoplant to a valve box located on top of the storage ring radiation shielding near the SRF cavity location. This MCTL supplies both liquid helium and liquid nitrogen to the CESR-B module, and also returns the cold helium gas to the cryoplant. A view of the system layout is given in Fig. 2. The valve box controls the flow of cryogens to and from the SRF cavity, which is connected to the valve box by three single-channel vacuum-jacketed (VJ) transfer lines approximately 4 m in length.

Figure 3 shows a simplified cutaway of the CESR-B module. The helium vessel has a volume of roughly 500 L, and is typically filled to around 490 L when operating. The helium vessel is suspended inside a vacuum vessel, along with two magnetic shields and a liquid nitrogen shield to reduce heat transfer to the helium. A HEX circuit siphons off a small amount of cold helium gas from the helium vessel, and circulates it around the thermal transition section of the input waveguide. The liquid nitrogen exhausted from the shield also coils around the waveguide before being exhausted to atmosphere. This provides a stable thermal transition from 4 K to room temperature. The single cavity is around 60 cm in diameter at the equator, and has a fluted beam tube on one side to help remove HOMs. CLS owns two of these cryomodules, and one is used as an off-line spare in the event of a cryomodule or cavity failure.

## SYSTEM PROBLEMS

While the CLS SRF cryosystem has generally performed reliably, there have been a few issues that have created unexpected downtime for the facility. Two MCTL failures on the cold gas return line caused a total of 6 weeks of unplanned downtime on 2007 and 2008. A series of compressor airend failures also resulted in around 2 weeks of lost time. These compressor failures were eventually traced to an incorrect maintenance procedure, which was due to a combination of inexperience in maintenance technicians combined with a misprint in the operating manual.

The compressor issues eventually caused oil to be forced into the return (low pressure) side of the coldbox. This resulted in three more weeks of unplanned downtime in autumn of 2012 while the coldbox was flushed with acetone and then warm dry nitrogen. Around 15 L of oil was removed from the return side of the coldbox heat exchangers during this procedure.

In January 2013 the cryomodule began to leak helium into the cavity vacuum. This forced a three week shutdown as the cryomodule was removed and the spare cryomodule was installed in the storage ring. Conditioning of the spare cryomodule took longer than expected after eight years of storage, and it was almost six months before a full beam current of 250 mA was again


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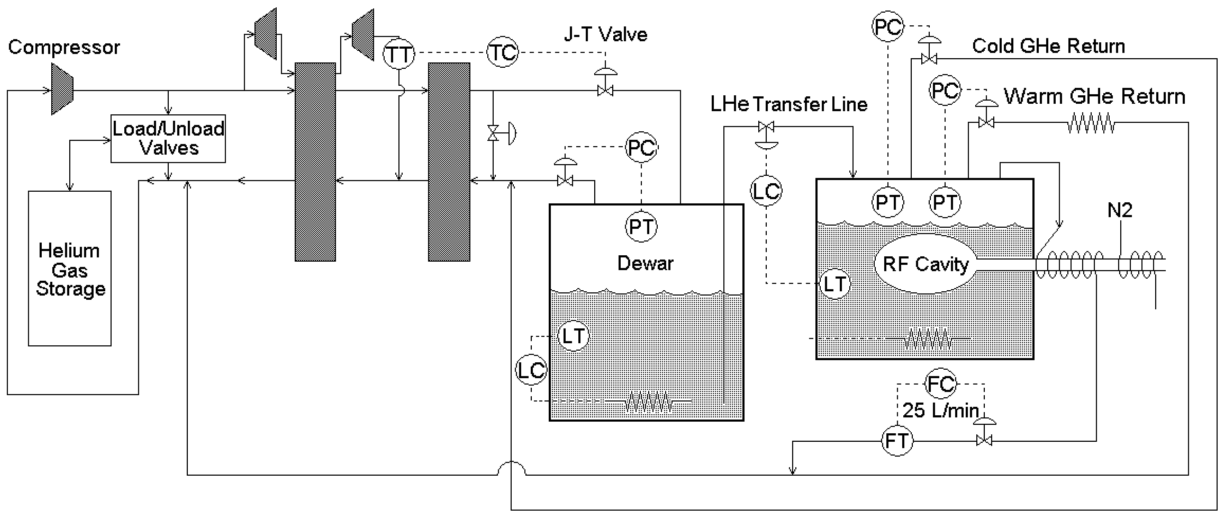


Figure 1: Schematic diagram of the CLS SRF cryogenic system.

realized. The damaged cryomodule was repaired at Research Instruments in Germany, where it was discovered that the source of the leak was the indium seals on the two small RF feedthroughs located on the niobium portion of the waveguide and on the round beam tube of the cavity. After repair, the module was tested at Diamond Light Source in the UK before being returned to CLS.

In the spring of 2015 the pressure in the insulation vacuum on the installed cryomodule began to rise. Maximum pumping was applied, and the unit survived to the spring shutdown with very little unplanned downtime. The issue turned out to be a large O-ring, and the groove design was modified and the O-ring changed out at CLS during the scheduled spring shutdown.

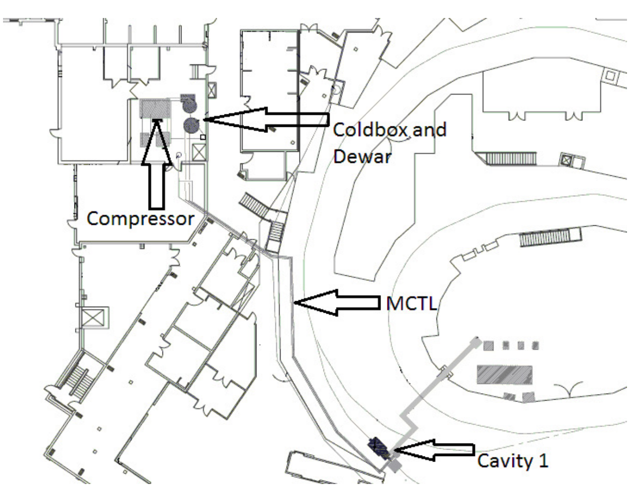


Figure 2: The 52 m MCTL layout for the existing system.

## THE UPGRADE PROJECT

Due to the problems listed in the previous section, and the possibility of future problems resulting in extended unexpected downtime periods, CLS has decided to undertake an upgrade to the SRF cryogenic system. System downtimes when there are problems are lengthy, as system components take days to warm up and cool down and lead times for failed items can be significant. Cavity conditioning is also an issue, as it can take months for beam currents to return to normal operating levels after installing a fresh cryomodule in the storage ring.

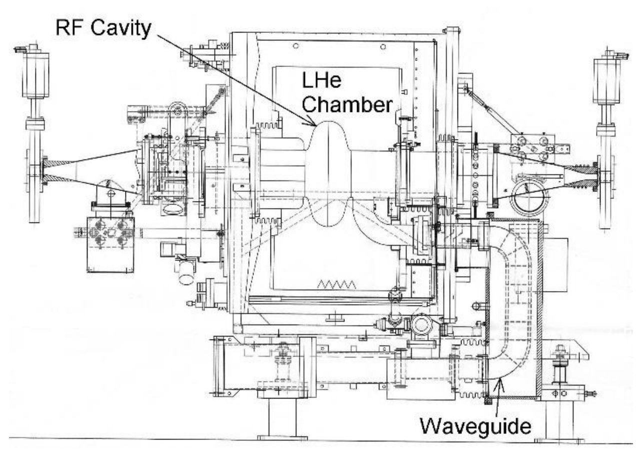


Figure 3: Cutaway view of the CESR-B SRF cryomodule.

The approach to the upgrade is largely based on past problems with the system, and also on weaknesses that have not yet caused issues but have the potential to in the future. The upgrade consists of:

- A spare helium compressor, ORS, and GMP,
- Installation of the spare cryomodule in the storage ring,

- replacement of the MCTL and valve box with 2 new MCTLs and valve boxes, and
- the move of the coldbox and dewar to the top of the storage ring radiation enclosure.

Addition of the spare compressor, ORS, and GMP is structured so that either the new compressor or the existing compressor can be operated with either the new ORS/GMP unit or the current ORS/GMP. This ensures that even if there are issues with "compressor 1" and "ORS/GMP 2" at the same time, the system can continue to operate. The ability to operate full time, 365 days per year will also allow CLS to keep the cryomodules cold at all times, reducing thermal cycling which can cause problems with the cryomodules.

The relocation of the coldbox and dewar to the top of the radiation enclosure increases the length of room-temperature piping required, but significantly reduces the length of MCTL necessary. Figure 4 shows the layout for the proposed upgrade. Reducing the length and complexity of the MCTL is anticipated to reduce the risk of MCTL failures in the future, and has the added benefit of reducing total heat load to the system. The move of the coldbox and dewar also creates the necessary space in the compressor room to add the second compressor, ORS, and GMP.

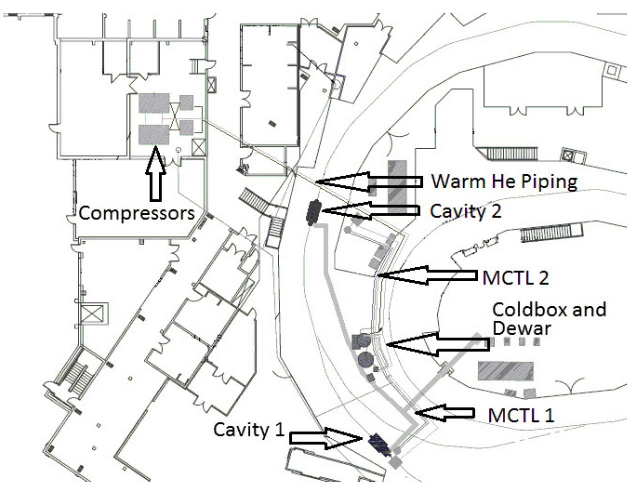


Figure 4: Layout for the proposed system upgrade.

The cryoplant was originally selected to have the capacity to operate two CESR-B modules, and therefore it was anticipated that the current coldbox and dewar would not require replacing. Subsequent testing has confirmed this, as the existing cryoplant has been refrigeration-load tested to a minimum of 374 W at 4.4 K. The anticipated cryogenic load, including contingency, for the proposed two-cavity system is 337 W, which gives a margin of error of almost 40 W on the cryoplant. This is technically feasible, but will require strict testing of components to ensure the cryogenic load is not excessive.

Placing the spare cavity in the storage ring has several positive impacts. While both cavities must be kept cold during beam operation, detuning one cavity can allow operation with only the other. The idea, though, is that both will be used under normal operation, reducing the power put to the beam through each cavity and lowering stress on the RF windows. In the event that one cavity has a cryogenic failure it can be removed, a spool piece inserted, and storage ring operation can be restarted. The fact that installation of the spare cavity is not required in this situation (it is already in-line) will save approximately one to two weeks of downtime should this occur. In addition, with both cavities operating both are being conditioned, and if one fails the time involved in conditioning the other cavity to bring it up to the 2.05 MV operating range is much less. This effect will also reduce the number of partial warm-ups required to eliminate contaminants from the cavity, meaning less stress for the entire cryogenic system.

With two cavities in the ring, there will be a need for two separate MCTLs and two separate valve boxes. Two conceptual designs have been generated for the MCTLs, one consisting of typical rigid transfer lines and one consisting of semi-flexible units. Significant conceptual work has been done on the valve box design. Phase separating vessels have been added for the helium and nitrogen flows to reduce the impact of gas breakout on cavity operation, and additional instrumentation has been placed to provide temperature and flow data, particularly during cool-down. Both valve boxes are to be new so that the design and function of each will be the same.

Since CLS acquired the CESR-B modules in 2003, there have been upgrades to the control racks used to operate the cavities. For the upgrade CLS plans to purchase and install two new cavity controls racks. As with the valve boxes, by keeping the controls for both cavities the same it will simplify operation by ensuring common procedures for both cavities, and will help with redundancy as the valve boxes and controls will be interchangeable between cavity modules.

Last but not least, a liquid nitrogen phase separator is to be implemented for the cryoplant and cryostat liquid nitrogen supply. CLS technicians have observed fluctuations in the RF that have been attributed to the liquid nitrogen flow. When the 40,000 L liquid nitrogen dewar is refilled by the liquid nitrogen vendor, there are substantial pressure fluctuations in the liquid nitrogen system that cause difficulties in flow control of liquid nitrogen through the cryostat. It is suspected that this variation in flow causes shifts in temperature in the thermal transition region of the waveguide. These shifts then affect the phase to the cavity, and the cavity requires tuning to maintain proper operation. The liquid nitrogen phase separator should insulate the SRF cryogenic system from nitrogen system pressure fluctuations, allowing smooth operation of the SRF cavity regardless of dewar filling or other liquid nitrogen system events.

## ANTICIPATED BENEFITS

Table 1 lists downtimes associated with various cryogenic system failures before and after the upgrade project. Currently, a compressor failure requires CLS technicians to warm up the entire system, repair the


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compressor, pump and purge the cryoplant and cryostat, and then cool down the system again. This typically takes between 3 and 7 days, depending on the work required to repair the compressor, and could take longer if there was a compressor problem for which CLS could not obtain spare parts in a timely fashion. With the second compressor in-line as proposed for the upgrade, the downtime in event of a compressor failure is reduced to less than one hour. The upgraded system will allow CLS technicians to simply valve the system over to the spare compressor, and restart the cryoplant. This can be done in a few minutes once the problem has occurred and the proper people have been brought in to do the switchover, meaning the coldbox does not have to be pumped and purged to remove contaminants that are released by the coldbox adsorbers as the coldbox warms. The spare ORS and GMP will have the same impact.

Table 1: Possible Failures and Associated Downtimes

| Event | Current System | Proposed System |
|---|---|---|
| Compressor Failure | 3 to 7 days | < 1 hour |
| MCTL Failure | 2 to 4 weeks | 7 days |
| Cryomodule Failure | 2 to 4 weeks or more | 7 days |
| Conditioning After Cryomodule Failure | 6 months | 1 month (estimated) |

MCTL failures have resulted in multiple weeks of downtime at CLS in the past. While the beam cannot be run with one cryomodule warmed up, with two cryomodules installed after the upgrade it is possible to remove one cryomodule and still operate at the normal 250 mA beam current. CLS experience demonstrates that warm-up and removal of a single cryomodule takes around 5 days, and another two days are assumed for installation and proper pump down of a spool piece to replace the cryomodule in the storage ring. Therefore an MCTL failure should result in around 7 days of downtime after the upgrade project. It should be noted that the design of the upgrade allows one cryomodule to remain cold while the other is warmed and removed. This not only avoids placing extra thermal stresses on the cryomodule remaining in the ring, but reduces downtime because the remaining cryomodule does not need to be cooled down.

Cryomodule failure has a similar impact to MCTL failure. Currently, when a cryomodule fails it must be removed from the ring and the spare cryomodule must be installed. This typically takes a minimum of two weeks, and can take up to three weeks if installation issues are encountered. In addition, there is a risk that the spare cryomodule may have developed an issue while in storage, or during transportation to CLS, which means that after installation there may be additional repairs required that increase the downtime. In the worst case, the spare cryomodule may need to be returned to Germany for service as well, resulting in downtime of months or even years. Having both cryomodules in the storage ring means that both are known to be functional, and means that removal of a failed cryomodule will result in the same downtime as that required for a failure in an MCTL.

After the cryomodule failure in January 2013, it took several months to return the storage ring to its normal operating current of 250 mA. This was because the spare SRF cavity required months of conditioning to return to full voltage operation. Figure 5 shows the peak beam current as a function of calendar time at CLS after the module replacement.

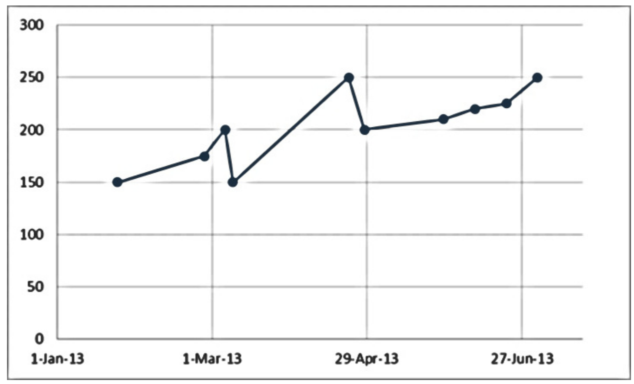

Figure 5: Peak beam current over time after cavity module replacement in January 2013.

CLS routinely runs 2 to 2.4 MV gradients in the single CESR-B cavity in the storage ring, and 260 kW of RF power or more. These high power and high voltage values demand that the cavity be very well-conditioned, which takes time. With the spare cavity installed and operating, as is proposed for the upgrade project, the cavity will be better conditioned. That way, if one cavity is removed and the other must run on its own it will require much less conditioning to reach maximum voltage and power.

## PROJECT STATUS

The idea of a cryogenic system upgrade at CLS has been floating around for several years, but the compressor and cryostat problems in late 2012 and early 2013 increased the urgency for such an upgrade. The conceptual design was completed in late 2013, and project schedule and budget were developed in early 2014 based on this.

Due largely to the assignment of engineering resources to other high-priority projects, the cryogenic system upgrade has progressed more slowly than desired. However, purchasing of major cryogenic components is scheduled to be completed by the end of 2015. With proper resourcing the installation of equipment should begin in mid-2016, and preliminary piping and wiring should be in place by mid-2017. The coldbox and dewar move is scheduled to occur during the autumn shutdown at CLS in 2017, and commissioning should take place in November and December 2017. Commissioning will likely continue to spring shutdown of 2018, as certain commissioning tasks cannot be completed in time to keep the autumn shutdown to a reasonable length.

## CONCLUSION

CLS is in the process of a major upgrade to the storage ring SRF system. This upgrade will add a second in-line spare compressor, a second operating SRF cavity in the storage ring, and new MCTLs and valve boxes. The coldbox and dewar will also be moved onto the storage ring radiation enclosure, much closer to where the liquid helium is required.

The upgrade project is designed to minimize downtime in the event of cryogenic system failures. It also reduces the risk of extended downtime events. The proposed design allows failed equipment to be extracted and the system to be restarted. Failed equipment can then be repaired while the system is back in operation, making downtimes not only shorter but making the lengths of downtimes more predictable.

The project is nearing the end of the design stage and entering the purchasing stage. Higher priority projects at CLS have extended the schedule beyond what was initially proposed, and completion is anticipated in late 2017.

## REFERENCES

[1] E. Chojnacki and J. Sears, "Superconducting RF Cavities and Cryogenics for the CESR III Upgrade," SRF 990716-09, SRF Reports, 1999.

[2] A. Sitnikov, et al., "National Synchrotron Light Source II cryogenic plant at BNL," Diamond Light Source Proceedings, 1, e62 doi:10.1017/S2044820110000584, 2011.

[3] R. Bate, et al., "The Diamond Light Source RF System," Proceedings of the 11th Workshop on RF Superconductivity, SRF2003, Lübeck, Germany, http://jacow.org/




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