# COMMISSIONING AND OPERATIONS RESULTS OF THE INDUSTRY-PRODUCED CESR-TYPE SRF CRYOMODULES

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*Abstract*

Upon signing a technology transfer agreement with Cornell University, ACCEL began producing turn-key 500 MHz superconducting cavity systems. Five such cryomodules have been delivered and commissioned to date. Four of them are installed in accelerators for operation (two in CESR and one each in Canadian Light Source and Taiwan Light Source) and one serves as an off-line spare at CLS. One more cryomodule is scheduled for testing in early 2005. It will be a spare unit for TLS. Three cryomodules for DIAMOND Light Source are being fabricated at ACCEL. The commissioning results and operational experience with the cryomodules in CESR, CLS and TLS are presented.

## INTRODUCTION

Single-cell superconducting cavities are well suited for high average beam current storage rings [1]. They provide effective damping of the higher-order modes. The negligible dissipation of RF power in the cavity walls means efficient transfer of the RF power to the beam. Their capability to operate at high (as compared to normal-conducting systems) accelerating voltages and to transfer high power to the beam reduces the total number of required cavities.

The first such cavities were developed for high energy physics colliders CESR [2] and KEKB [3]. Successful and reliable operation of the first SRF systems for high current beams stimulated interest of other laboratories and industry to this technology, especially in application to the third generation light sources. As these relatively small new user facilities are built very often on “green sites”, they have limited infrastructure and capabilities of doing accelerator related R&D and often lack of expertise in superconducting RF. The main stopping points in adopting new technology for many of them were reluctance to invest significant amount of resources in R&D and infrastructure and desire to purchase ready-to-use products from industry. The turning point in the attitude toward superconducting RF came in 2000 when Cornell University and ACCEL pioneered in concluding the technology transfer agreement for industrial production of 500 MHz CESR B-cell cryomodules (Figure 1) and NSRRC in Taiwan became the first laboratory to order two turn-key superconducting accelerator modules for the Taiwan Light Source (TLS) upgrade [4], followed shortly thereafter by another order of two cryomodules by the Canadian Light Source (CLS). Later on DIAMOND facility (DLS) in UK followed the suit by ordering three modules [5]. Typical operating parameters of an ACCEL-produced cryomodule are listed in Table 1.

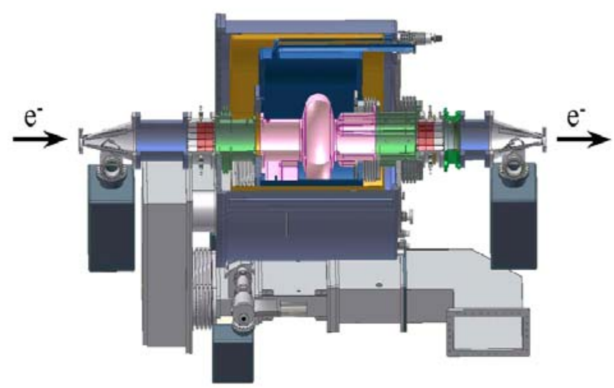


Figure 1: CESR-type cryomodule for TLS.

Table 1: Typical operating parameters of the SRF cryomodule [5].

| Parameter | Value |
|---|---|
| Operating frequency | 499.6 – 500.0 MHz |
| Tuning range | ± 125 kHz |
| Tuning resolution | 10 Hz |
| Helium vessel pressure | 1200 ± 1.5 mBar |
| Operating temperature | 4.5 K |
| Accelerating voltage (gradient) | > 2.4 MV (8 MV/m) |
| $Q_0$ at 8 MV/m | > $7\times10^8$ |
| Standby losses at 4.5 K | < 30 W |
| Cryogenic losses at 4.5 K and 8 MV/m (including standby losses) | < 120 W |
| $Q_{ext}$ of the input coupler | $2.3 \pm 0.3 \times10^5$ |
| Maximum power transferable to the beam | > 200 kW |

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## TEST RESULTS

Subcomponents like cavities and RF windows are tested separately prior to assembly of the cryomodules. Nine cavities (two each for Cornell, NSRRC and CLS and three for DLS) have been fabricated by ACCEL so far and tested in a vertical cryostat at Cornell with very good, reproducible results (Figure 2). The high-power windows are conditioned on a test stand at Cornell up to a maximum of 125 kW at full reflection and up to 250 kW in traveling wave mode (limited by the available RF load). If needed, the windows can be conditioned further with the reduced duty cycle in traveling wave mode up to 400 kW.

After assembly completion the cryomodules are delivered to respective facilities and tested on site. The cryomodule test results to date are shown in Figure 3.

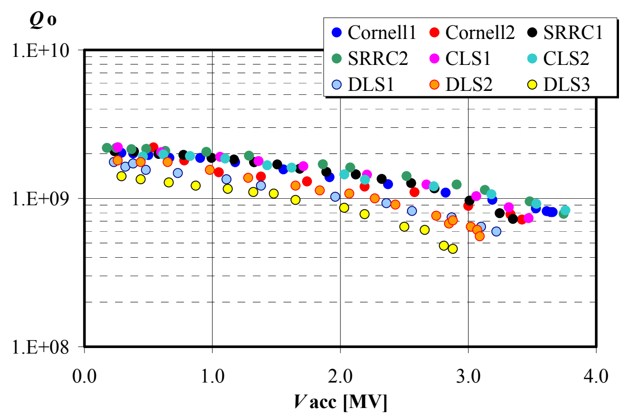


Figure 2: Vertical test results of ACCEL produced cavities.

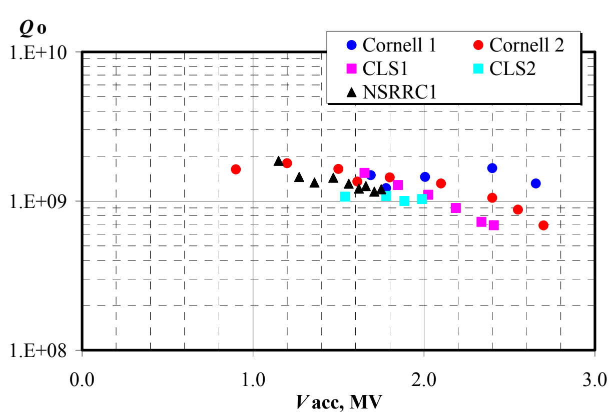


Figure 3: Cryomodule test results.

## COMMISSIONING AND OPERATION

Five cryomodules have been commissioned and are in operation: one at NSRRC and two each at Cornell and CLS. In this section we describe our experience with these cryomodules.

### *CESR*

Two cryomodules were built by ACCEL for CESR. The first one was installed in the machine and commissioned in September of 2002. The second cryomodule has been in operation since May of 2004. Both units perform well, operating at accelerating voltages in the range from 1.4 MV (for CESR-CHESS synchrotron light source regime at beam energy of 5.3 GeV) to 2.4 MV (for CESR-c collider regime at 1.55 to 2.5 GeV). RF system is configured with one klystron per two cavities for both regimes of operation. In CESR-CHESS mode SRF cryomodules have to support maximum beam current of 500 mA by delivering up to 160 kW of RF power per cryomodule.

CESR-c operation is radically different for RF system as the emphasis is not on delivering very high RF power to beams, but on providing very high RF voltage to produce short bunches and high synchrotron tune [6]. RF power required for CESR-c is very moderate: 10 to 40 kW per cryomodule depending on the energy of the experiment. To reduce RF power consumption it was proposed operating some of CESR superconducting cavities in a passive mode. Experiments were performed to prove the validity of this approach [6]. More recently, three-stub waveguide transformers were used to raise external quality factors from nominal values of $2\times10^5$ to $4\times10^5$. Operating at higher *Q* did not have any adverse effects on amplitude and phase stability of cavity fields.

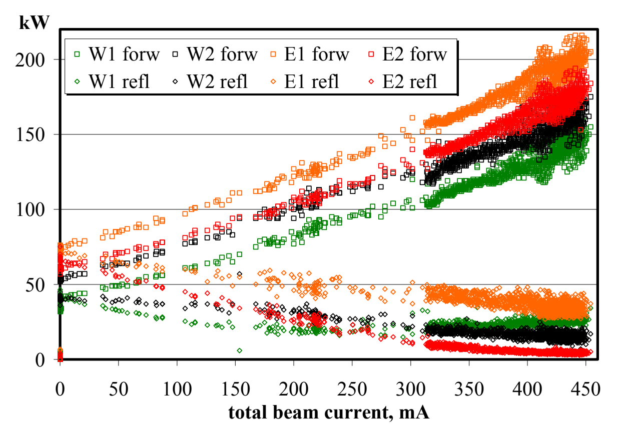


Figure 4: Typical plot of RF power (forward and reflected) dependence on total beam current for four superconducting cavities in CESR (CESR-CHESS).

### *Taiwan Light Source*

The first cryomodule for TLS was commissioned during fall of 2004 and has been in operation since then. The cryomodule operates at accelerating voltage of 1.6 MV and supports beam current of 200 mA with 50 kW of forward RF power. 280 mA was reached during machine studies. The cryomodule demonstrates reliable operation at the nominal beam current (Figure 5). The trip rate of the complete RF plant (cryomodule, RF transmitter, RF feed-line, low-level controls, etc.) is 1.5 trips per week. Most of the trips are associated with false alarms from window and circulator arc detectors, quench detector trips due to fast beam dumps. The goal is to reduce trip rate to one trip per month.

The beam current is limited at present by the available RF power. A new 100-kW klystron will be in operation soon. This will eventually allow increase of the beam current up to 500 mA with the goal for 2005 is to reach 350 mA.

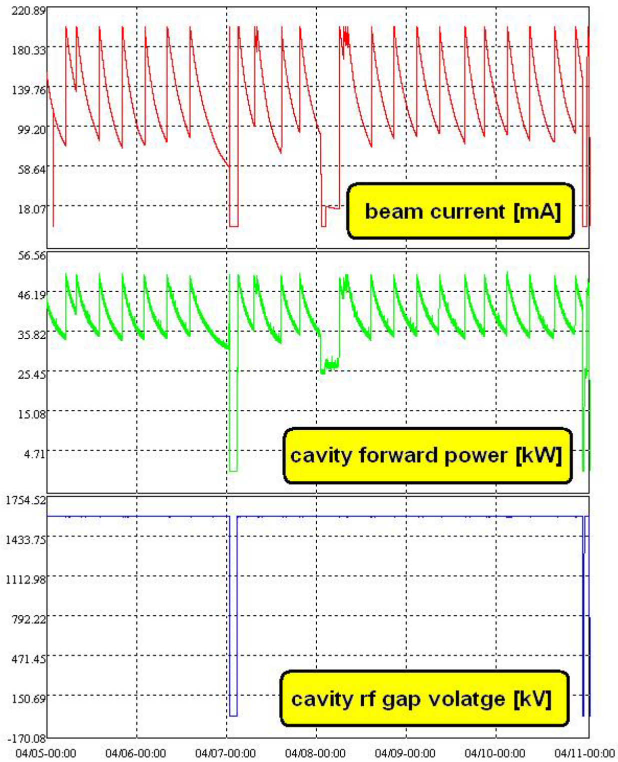


Figure 5: Typical operation of the TLS.

### *Canadian Light Source*

The first CLS cryomodule was commissioned during the summer of 2003, and put into operation for the storage ring commissioning that started in September 2003. During the following year, the cavity was usually operated at 1.8 to 2.2 MV, with some operation at 2.4 MV. The maximum beam current was 205 mA, with a forward power of over 200 kW. More typically, the storage ring has operated reliably with 100 to 150 mA. When the cavity voltage is under 2.0 MV, essentially all trips are due to the external machine protection system that trips the RF for a fast beam dump. At higher voltage and beam current, the vacuum pressure at the window is prone to sudden increases that cause an arc and RF trip. RF conditioning with beam helps to raise the threshold of these trips, but the process results in frequent beam trips at high current. Most of the problems encountered were typical of the commissioning phase of a major facility. In particular, a partial or complete warm-up was needed several times to keep the vacuum in good condition during vacuum conditioning of the storage ring with beam.

The second CLS cryomodule was delivered in August 2004, and installed in place of the first module in November 2004. The first module now serves as an off-line spare cavity. The second module was placed into service in early January 2005 after only 6 hours of pulse conditioning, achieved a voltage of approximately 1.8 MV. Although this module has now also been conditioned to 2.4 MV, it has typically been operated at 2.0 to 2.2 MV with beam current up to 160 mA.

## SUMMARY

With the technology transfer to industry (ACCEL) the superconducting RF technology has become the technology of choice for new projects at laboratories, which did not have prior SRF experience. Three third generation light sources (Taiwan Light Source, Canadian Light Source, DIAMOND) had chosen CESR B-cell cryomodules for their RF systems. Five cryomodules manufactured by ACCEL have been delivered and commissioned. Four of them are installed in accelerators for operation (two in CESR and one each in CLS and TLS) and one serves as an off-line spare at CLS. The spare cryomodule for TLS will be commissioned soon. Fabrication of cryomodules for DIAMOND is in progress at ACCEL. The delivery and commissioning of the first DLS unit is expected later this year.

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