

HoBiCaT—A TEST FACILITY FOR SUPERCONDUCTING RF SYSTEMS*

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Abstract

Superconducting TESLA cavities are planned for the booster and linac sections of the CW BESSY FEL. A number of challenges and unknowns must be investigated prior to finalizing the design and parameter list. These include the demonstration of long-term, high-gradient CW cavity and RF-coupler operation, the measurement and reduction of microphonics, the precise RF regulation of very-narrow-bandwidth cavities, and the investigation of the cryogenic parameters such as optimal bath temperature and achievable pressure stability. To address these issues, BESSY is constructing a horizontal cavity test facility called HoBiCaT to enable rapid-turn-around tests. This facility can accommodate 9-cell TESLA cavity pairs with all the required ancillary, including the helium tank, tuner, input coupler, HOM couplers, and monitor probe. Piezo stacks will be integrated in the tuner system to both study and cancel out microphonics to minimize the required RF power. First cavity tests are planned for early 2004.

MOTIVATION

TESLA superconducting radio-frequency (RF) cavities were originally developed for use in the TESLA linear collider and the TESLA X-FEL.[1] These machines are planned for high-energy operation and require high accelerating gradients to limit their lengths. The refrigeration cost dictates that these machines be pulsed (1 ms) with a 10 Hz repetition rate. Correspondingly the peak beam loading is very high.

In part due to the success of the TESLA Test Facility (TTF) at demonstrating the reliable operation of TESLA equipment, a number of proposals for CW linacs are now based on this technology. They include the BESSY FEL[2], the Cornell Energy-Recovery Linac (ERL)[3], and the MIT-Bates X-ray Laser[4]. These machines are designed for moderate energies (2 – 5 GeV) with little beam loading, so that CW operation can be realized.

Although much of the TESLA technology can be applied directly to CW machines, new issues uniquely related to CW operation (and not necessarily addressed at TTF) now need to be investigated.

BESSY therefore is constructing a horizontal test facility named HoBiCaT (Horizontal Bi-Cavity Test-facility) that permits rapid-turn-around testing of TESLA equipment. Its design is based upon the CRYHOLAB[5] and CHECHIA[6] systems developed at the Orsay and Saclay institutes, respectively.

Table 1: Parameters for the HoBiCaT test facility at BESSY

Parameter	Value
Mechanical	
Interior length	3.5 m
Interior diameter	1.1 m
Number of cavities	2 9-cell cavities or 1 superstructure
Main Cryogenics	
Temperature	1.5 – 2.2 K, 4.2 K
Capacity	80 W/150 W (1.8 K/4.2 K)
Pressure stability	±0.1 mbar/1 mbar (1.8 K/4.2K)
Static losses	3 W @ 1.8 K
Secondary Loops	
Table cooling	4.5 K
Cavity fill	4.5 K
Coupler cooling	4.2 K – 20 K
Radiation shield	77 K
Vacuum Pumps	
Suction pressure	14 mbar
Speed	6400 m ³ /hr
RF Power	
Frequency	1.3 GHz
Power	10 kW

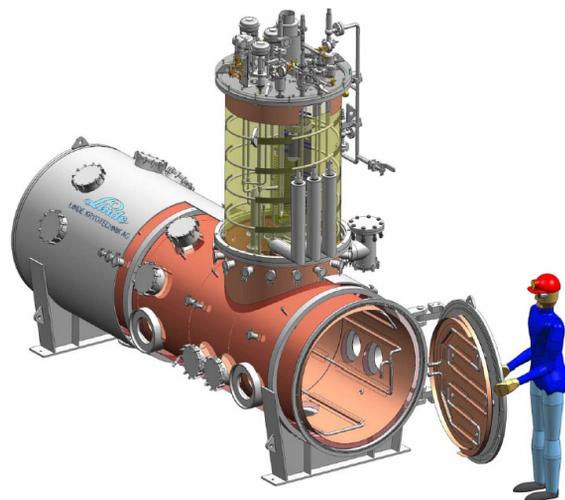


Figure 1: The HoBiCaT cryostat.

HOBICAT SYSTEM

The HoBiCaT test facility includes a cryostat, feedbox, helium refrigeration plant, rf power supply and 2 TESLA cavities and associated ancillary equipment. The main system parameters are summarized in Table 1.

Cryostat Design

Figure 1 depicts the HoBiCaT cryostat. The horizontal vacuum tank has interior dimensions of 1.1 m (dia.) and

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3.5 m (length). These are sufficient to accommodate 2 complete TESLA 9-cell cavities (or one TESLA superstructure) with RF couplers, tuners, and helium tanks. The large-diameter tank can also accommodate bigger cavities (up to 500 MHz).

The cavity units slide into HoBiCaT on a rolling table. Power couplers penetrate the vacuum vessel via two of the four large feedthroughs shown on the side, their arrangement being the same as on TESLA modules. Numerous diagnostic ports are provided for additional instrumentation. Doors at either end allow for quick access to the unit. Cooldown-to-warmup times are expected to be around 5 days.

A feedbox sits on the main vessel. It receives 4.2-K liquid helium (LHe) from the BESSY cryoplant and supplies the cavities with 1.8–2.2 K or 4.2 K LHe.

Cryogenics

A 180 l/hr, 4.2-K refrigeration plant (TCF50), as shown in Fig. 2 (top), is currently in operation at BESSY-II, supplying helium to wavelength shifters and a 3rd harmonic superconducting cavity. This system will also provide liquid helium for HoBiCaT.

Vacuum pumps for superfluid operation have also been procured (Fig. 2, bottom). Their capacity is sufficient for 80-W operation at 1.8 K, although lower temperatures (down to 1.5 K) at reduced power will also be possible.

Figure 3 illustrates the cryogenic scheme of the HoBiCaT cryostat. 4.2-K helium from the cryogenic plant is collected in a 50-liter vessel in the feedbox. From here, helium passes through a heat exchanger and is expanded via a JT valve into a 2-phase line. This in turn supplies the two cavity helium vessels with He-II. A reservoir with heater and level meter at the end of the two-phase line is used for level control and to balance the dynamic heat load of the cavities. The layout of this system was intentionally chosen to mimic that of the proposed BESSY FEL accelerating modules, so that the cryogenic aspects of CW cavity operation can be studied.

Pressure regulation is possible in the temperature ranges 1.5 K – 2.2 K and at 4.2 K. The specified pressure stability is ± 0.1 mbar at 1.5 K – 2.2 K and ± 1 mbar at 4.2 K.

Additional, secondary, cooling loops exist within HoBiCaT:

- A 4.2-K supply line to fill the helium vessels from the bottom during cooldown
- A second 4.2-K line to cool the table supporting the cavities.
- A helium-gas line that cools heat intercepts on the input couplers. A heater allows the temperature to be varied from 4.2 K to 20 K.
- A liquid nitrogen loop to cool the 77-K radiation shield.

Static losses, not including those associated with the diagnostic equipment, are expected to about 3 W at 1.8 K.



Figure 2: Linde TCF-50 Cold-box for 180 l/hr, 4.2-K LHe production (top), and Leybold vacuum pumps for 80-W, 1.8-K HoBiCaT operation being installed in the pump room (bottom).

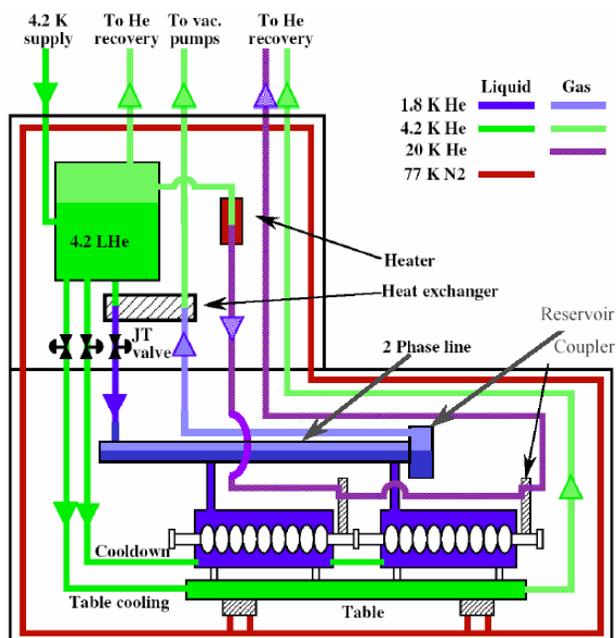


Figure 3: HOBICAT cryogenics.

RF Power

The main RF power source will be a 10-kW CPI klystron adapted from the CEBAF 1.5-GHz design scaled to 1.3 GHz. Although 15 kW of rf power are envisaged for the BESSY FEL, 10 kW are sufficient for HoBiCaT tests because beam loading is absent. Microphonic detuning up to 35 Hz at 20 MV/m can be compensated with 10 kW. An additional 1-kW solid state amplifier is available for cavity Q measurements with a phase-locked loop.

Cavity Equipment

Production of two complete cavity units for testing in HoBiCaT is nearly complete. Each unit includes a

- TESLA 9-cell cavity
- Helium tank
- TTF-III input coupler[8]
- Tuner (“TTF-style” for Unit A, “blade-style”[9] for Unit B).

The TTF-III coupler was modified slightly to enhance its coupling range, which now runs from $2 \times 10^6 - 2 \times 10^8$. An additional 3-stub tuner in the waveguide feed permits that range to be extended further into the 10^9 range[10] so that accurate Q measurements by power decay curves will be possible with the 1 kW amplifier. These results can also be used to calibrate alternative Q measurements via helium boil-off which will be used whenever the cavity is greatly overcoupled.

TEST PROGRAM

Nearly all equipment is either presently in house, or will be delivered by 12/2003, when the HoBiCaT cryostat will be completed. Commissioning is expected to begin early 2004 in several stages. First, the cryogenics will be tested without the cavities. Low power cavity tests with the 1-kW amplifier will then take place in parallel with off-line commissioning of the klystron. Finally, by Spring 2004, we intend to operate the cavities in conjunction with the 10-kW klystron

Following are some issues that will then be studied:

1. Measurement of the Q of a complete cavity unit (including all ancillary devices) as a function of voltage and temperature. This information is needed to optimise the operating parameters of the BESSY FEL.
2. Determination of the CW power limit of the (cold) TTF-III input couplers under standing-wave conditions.
3. BESSY-FEL cavities have a very narrow bandwidth because the beam loading is small, necessitating a high-gain RF feedback system. The gain limits and attainable cavity-voltage stability must be measured.
4. Microphonic detuning dominates the rf-power budget. Passive measures to reduce the microphonics will be investigated. This includes the mechanical

characterization of the two tuner designs and their effect on the mechanical modes of the cavities.

5. A piezo stack integrated in the tuner is proposed to suppress the remaining microphonic detuning via feedback.[5] The feasibility of this scheme needs to be demonstrated with TESLA cavities. Measurements of the tuner transfer function are needed to design an effective feedback controller.
6. The dynamic cryogenic load can be as high as 40 W/cavity. Steady CW cryogenic operation and a high degree of pressure stability must be demonstrated.

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