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Development of a Cryogenic Calorimeter for Investigating the Heat Load of Superconducting Undulators

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Theme: Insertion Devices

Abstract:

Superconducting insertion device technology is a key emerging development for synchrotron radiation light sources. To optimize design of superconducting undulators, we designed the cryogenic calorimeter to simulate the working of superconducting undulators at variable magnetic gaps, to quantify the amount of beam-based heating of storage rings (SR). The calorimeter has been developed by Shanghai Synchrotron Radiation Facility (SSRF) and installed on storage ring of SSRF in this summer.

This paper describes the cryogenic system, mechanical structures and first online experiment. Also some measurement results are given in the paper.

1- Introduction

Comparing to conventional permanent insertion devices (IDs), superconducting insertion devices can enhance magnetic field strength signally. Therefore, superconducting IDs have been widespread applied in synchrotron light sources to increase the brilliance and photon energy. Beam-based heating, magnet measurement system working with cold magnet, and phase correction, are three key remaining issues to be resolved in the R&D of superconducting undulators [1]. Beam-based heat loads are dynamic heat loads which include image current, synchrotron radiation from upstream bending magnet, E-cloud and RF effects [2].

To optimize the design of cryogenic system and undulator magnet, LBNL and SSRF collaborate to build a cryogenic calorimeter to quantify beam-based heat load. The scientists of LBNL propose the original concept of cryogenic calorimeter [3]. SSRF is tasked with implementing the cryogenic calorimeter,

and first installation and experiments on SR of SSRF. FIGURE 1 shows the installed calorimeter in SR of SSRF.



FIGURE 1 Installed calorimeter in storage ring

2- Cryogenic system

The calorimeter is a cryogen free system which has simplicity and flexibility for the design of cryostat, and has easy maintenance [4]. It uses two sets of Pulse Tube cryocooler which has lower vibration comparing to Gifford-McMahon cryocooler [5]. One model SPR-082B of Sumitomo cold head and one model PT415 of CRYOMECH cold head cool the thermal shield and beam plates. The first stages of two cryocoolers cool the 50 K thermal radiation shield. Two paralleled beam plates are connected to the second stages of those cryocoolers via the measurement blocks. Beam plates should work below 15 K without beam. FIGURE 2 shows a schematic drawing of the cooling system.

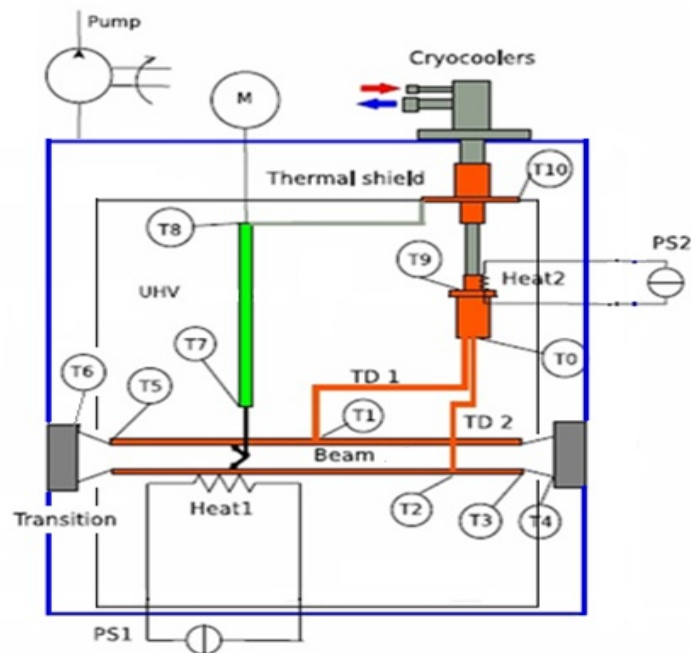


FIGURE 2 Schematic drawing of the cooling system

TABLE 1 lists estimated static heat loads which include traditional thermal conduction and thermal radiation. Two cryocoolers provide available cooling capacity with 2.5 W@4.2 K and 85 W@50 K. Without beam operation, cooling capacity has a certain amount of margin.

TABLE 1 Estimated static heat loads

Item	Type	4K Load [W]	50K Load [W]
Thermal Interception	Conduction	0.38	
50K-4K Radiation	Radiation	0.02	
Instrument Wires	Conduction	0.02	
Beam Plate Supports	Conduction		1.3
50K Shield Supports	Conduction		0.7
RF Transitions	Conduction		11.9
300K-50K Radiation	Radiation		23.6
Total		0.42	37.5

3- Mechanical structures

The calorimeter has been installed in the straight section of storage ring of SSRF. It mainly consists of two beam plates, two UHV sleeves, two Pulse Tube cryocoolers, one 50 K thermal shield and one UHV chamber. FIGURE 3 shows overall structure of this calorimeter.

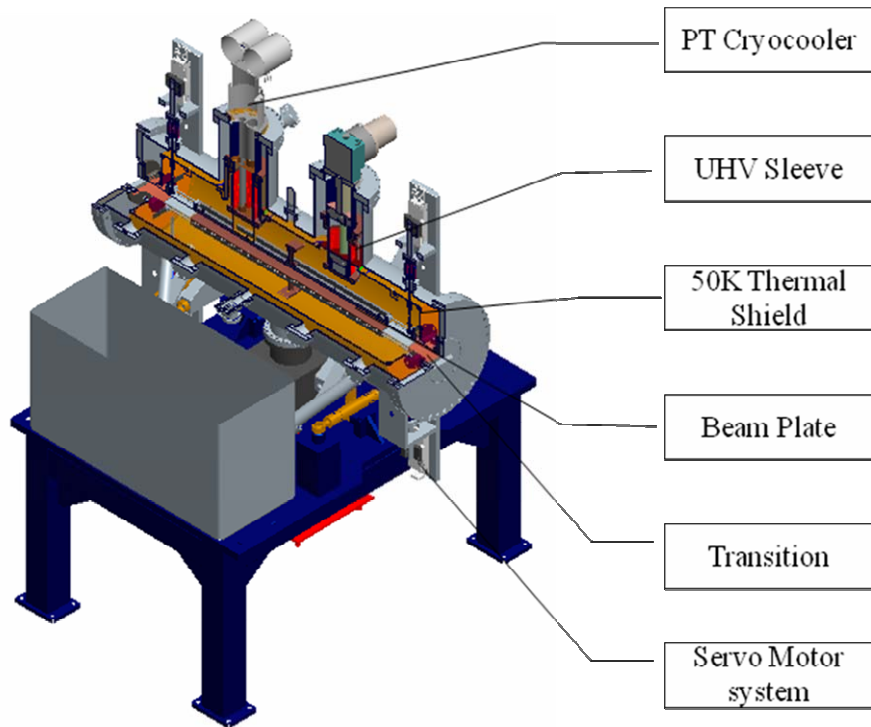


FIGURE 3 3D drawing of the calorimeter

Two paralleled beam plates which is 1 meter length and coated by 80 μm film of copper. When the electron beam goes through them, beam-based heat load will deposit on the copper films. FIGURE 4 shows the assembly structure of beam plates and measurement block.

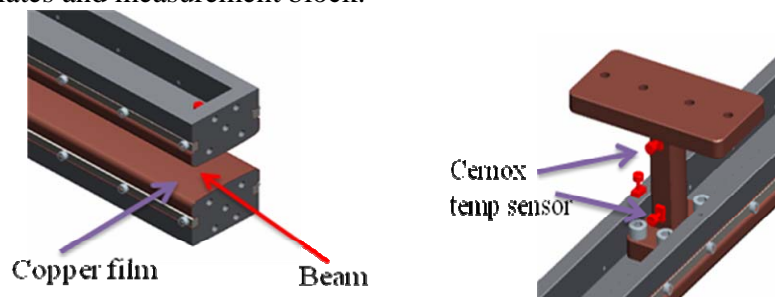


FIGURE 4 The assembly structure of beam plates and measurement block

UHV chamber is 1.4 meter length and 400 mm diameter. Its vacuum system uses one 400 L/s ion pump and two 400 L/s NEG pumps to meet the requirement of SR. UHV sleeve is a part of vacuum chamber. The goal of using UHV sleeve is to separate the UHV of beam chamber and HV of cryocooler. That means we can bakeout this system without cryocooler. Also it's convenient to maintenance of cryocooler. FIGURE 5 shows 3D drawing and photo of UHV sleeve.

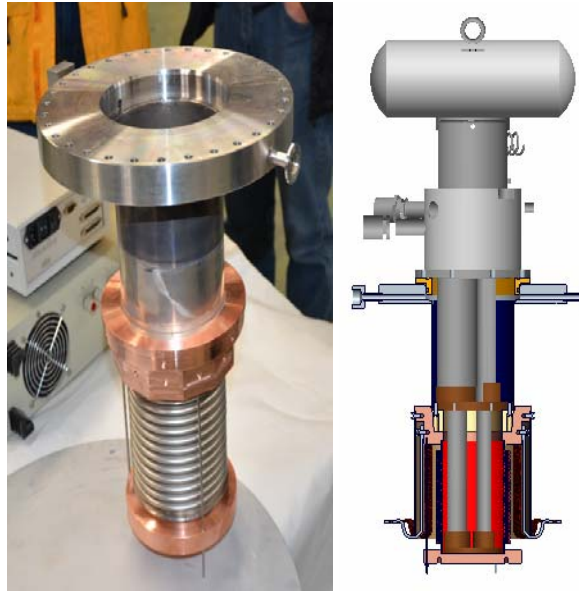


FIGURE 5 3D drawing and photo of UHV sleeve

4- First online experiment

This calorimeter uses 16 Cernox temperature sensors, 14 PT100 temperature sensors and 8 heaters. The Cernox sensors on the beam plates can show the temperature distribution. The Cernox sensors on the measurement block can measure the heat flux between cold head and beam plate. One temperature control loop of 2nd stage cold head can remain output of cooling power constant. FIGURE 6 shows the distribution of temperature sensors and heaters.

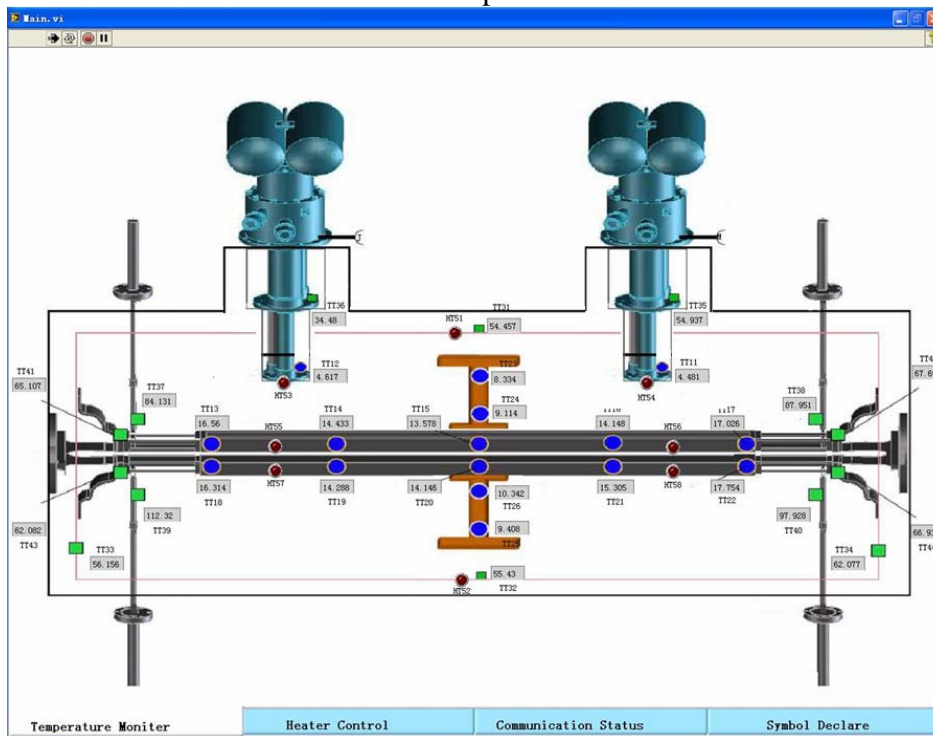


FIGURE 6 The distribution of temperature sensors and heaters

Since September of 2012, this calorimeter started to perform online experiment. After 24 hours cooling down, the temperature of 1st stage and 2nd stage reached stable condition. Without beam, thermal shield reached at 55 K, beam plates reached at 15 K and 2nd stage reached at 4.4 K. FIGURE 7 shows the curve of cooling down. FIGURE 8 shows temperature distributions on beam plate with and without beam. Temperature rising of beam plates could be as high as 25 K while 200 mA beam with decay pattern and 20 mm gap.

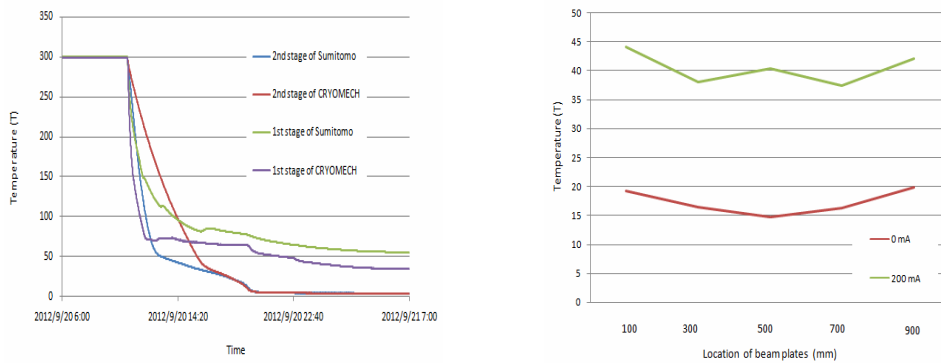


FIGURE 7 Curve of cooling down FIGURE 8 Temperature distributions on beam plate

5- Summary

With two cryocoolers of cooling system, the beam plates and thermal shield of this calorimeter can reach expected temperature. The first online experiment shows that beam-based heat load is higher than we expected. Further measurement and analysis will show the amount of beam-based heat load in following several months. That will help the design of cooling system and undulator magnet.

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