Fusion Engineering and Design 128 (2018) 163–167

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

The cooling test platform design for iter radial x-ray camera

Bin Zhang[a,b], Sheng Zhang[a,b], Yebin Chen[a,*], Liqun Hu[a], Shi Li[a], Keping Wu[a], Zhigang Zhu[a], Jinlong Zhao[a]

[a] Institute of Plasma Physics Chinese Academy of Sciences, Hefei, 230031, China
[b] University of Science and Technology of China, Hefei, 230026, China

ARTICLE INFO

Keywords:
Radial X-ray camera
Cooling test platform
EPICS

ABSTRACT

The Radial X-ray Camera (RXC) is a diagnostic in Equatorial Port 12 (EQ#12) of International Thermonuclear Experimental: Reactor (ITER). Normally, the operating temperature of detector on RXC system shall be lower than 75 °C. But the detectors on some part of RXC system will have to face a high temperature of 250 °C during baking of ITER, as a result of which case detectors will be easily damaged. Due to the harsh environment, cooling for RXC system is necessary. In order to verify the effect of gas cooling, the related research and experiments are being carried out.

This article focuses on the analysis of the architecture and heat transfer capacities of the cooling test platform. According to the analysis results, the solution of the cooling platform is introduced and a cooling test platform is established. Also, a Data Acquisition (DAQ) system is developed based on Experimental Physics and Industrial Control System (EPICS) framework. The experiment results based on the cooling test platform provide support for the cooling system design of RXC system.

1. Introduction

A radial x-ray camera (RXC) will be installed in the ITER EPP #12(middle drawer, DSM02) to measure the poloidal profile of the plasma x-ray emission [1].

RXC consists of internal and external camera modules. The detector on the RXC is a normal linear silicon semiconductor photodiode (Series 5T of Centronic Ltd., Craydon. United Kingdom), whose operating temperature shall be lower than 75 °C [2]. The main vacuum vessel where the internal camera will be installed would reach 250 °C during baking of ITER. Even in the normal operation phase, the environment temperature will be higher than 75 °C in which case the detectors could not survive. Normally, for each 10 °C increase on the detector, the dark current will be doubled [3]. Excessive temperature will not only damage the detectors of the internal camera, but also affect the performance of the detectors. Therefore, cooling system should be adopted to keep the detectors at room temperature. Gas cooling is one of the cooling methods. Helium is recommended by ITER as cooling medium in the cooling system for its good conduction of heat.

In this paper, a cooling test platform is developed so as to meet the cooling requirement for the internal camera detectors of RXC. Thermal load of the internal camera detectors is estimated. Also, the solution of equipment selection and test plan of the cooling test platform is presented. In order to verify the actual effect, a cooling test platform is built based on this scheme. The standard ITER Instrument and Control (I&C) architecture is deployed for data acquisition and control system of the cooling test platform. The test results show that the detectors' temperature can be limited to under 75 °C. It also provides support and reference for the cooling system design of RXC system.

2. Cooling test platform requirements analysis

During the baking of ITER, the ambient temperature of internal camera is about 250 °C. As the upper limit temperature of detector is 75 °C, for a safety margin, it is assumed that the temperature of detector should be reduced to 50 °C. Generally, there are three different ways affecting the heat of the detectors, the first one is the heat radiation from vacuum space, the second one is the heat conduction from stents that is used to fix the heat exchanger on the detector housing, and the last one is the heat convection. As the detectors of internal camera will be installed in the second vacuum vessel of ITER, the heat convection is negligible.

It should be noted that in order to protect the detector and limit the light path of X-Ray from the plasma, a detector housing which is molded with 316L stainless steel is used to hold the detector. The temperature of detectors will rise when detector housing absorbs the heat from vacuum space. Therefore, the surface of the detector housing is polished to improve heat reflection from vacuum space. To further

* Corresponding author.
E-mail address: chenyebin@ipp.ac.cn (Y. Chen).

https://doi.org/10.1016/j.fusengdes.2018.01.057
Received 21 January 2017; Received in revised form 28 September 2017; Accepted 23 January 2018
Available online 10 February 2018

Fig. 1. Heat exchanger and ceramic.

reduce heat absorption, Multi-layer insulation (MLI) with high reflectivity and low emissivity is applied to reflect thermal radiation from vacuum space [4–7].

The heat exchanger fixed tightly with the ceramic detector module is used to exchange the heat from detector by cooling medium. Meanwhile, the heat exchanger is fixed on the detector housing by four long and thin stents.

2.1. Thermal radiation power calculation

A testing camera is mounted inside the baking cell. Inside the testing camera there are 3 detector modules made with ceramic (see in Fig. 1) which is the same material as the package material of the detector. To obtain better effect of thermal reflection, more MLI are added to the outer surface and inner surface of detector housing. The heat of ceramic detector modules comes from the radiation of MLI and it is exchanged by helium in cooling copper pipe.

In this design, Q_{HE} represents the meaning of the thermal radiation power of a single heat exchanger. In order to calculate the maximum thermal power of the heat exchanger, it is assumed that the heat of the detectors is all transferred to the heat exchangers.

Theoretically, the heat radiation power of heat exchanger can be quantified in terms of its heat transfer coefficient U_{11}, temperature gradient ΔT_1 and area of ceramic(0.074 m × 0.015 m × 0.014 m) A_{CE}, so the total heat radiation power in three heat exchangers can be calculated as:

$$3 \times Q_{HE} = 3U_1A_{CE}\Delta T_1 = 3 \times 4\sigma T_1^{3}\frac{1}{(1/\varepsilon_{CE}+1/\varepsilon_{M}-1)}A_{CE}\Delta T_1 \approx 1.08\text{W} \tag{1}$$

Where

Q_{HE} is the radiation power of a single heat exchanger,

$U_1 = 4\sigma T^3\frac{1}{(1/\varepsilon_{CE}+1/\varepsilon_{M}-1)}$ is the heat transfer coefficient between two layers,

$ACE = 0.00375\,m^2$ is the area of ceramic,

$\Delta T1 = (250 - 50)K = 200K$ is the temperature gradient,

$\varepsilon_{CE} = 0.69$ is the emissivity of ceramic,

$\varepsilon_M = 0.028$ is the emissivity of MLI under vacuum condition,

$T_1 = {}^{523.15\,K + 323.15K}/_2 = 423.15K$ is the mean temperatures of MLI and ceramic,

$\sigma = 5.7 \times 10^{-8}\,Wm^{-2}K^{-4}$ is the Stefan-Boltzmann Constant.

The thermal radiation power of the copper pipe can be calculated as:

$$Q_{CT} = U_2A_{CT}\Delta T_2 = 4\sigma T_2^{3}\frac{1}{(1/\varepsilon_{CT}+1/\varepsilon_{M}-1)}A_{CT}\Delta T_2 \approx 14.21\text{W} \tag{2}$$

Where

$U_2 = 4\sigma T_2^3\frac{1}{(1/\varepsilon_{CT}+1/\varepsilon_{M}-1)}$ is the heat transfer coefficient between two layers,

$ACT = 2\pi rl = 2\pi \times 0.008 \times 3 \approx 0.151\,m^2$ is the area of cooling copper pipe,

$\Delta T2 = (250 - 50)K = 200K$ is the temperature gradient between the MLI and cooling copper pipe,

$\varepsilon_{CT} = 0.5$ is the emissivity of cooling copper pipe,

$\varepsilon_M = 0.028$ is the emissivity of MLI under vacuum condition,

$T_2 = {}^{523.15\,K + 323.15K}/_2 = 423.15K$ is the mean temperatures of MLI and cooling copper pipe,

$\sigma = 5.7 \times 10^{-8}\,Wm^{-2}K^{-4}$ is the Stefan-Boltzmann Constant.

Fig. 2. Stents structure.

2.2. Thermal conduction power calculation

Heat conduction is one of the important factors which lead to temperature rising. As shown in Fig. 2, heat is transferred from detector housing to heat exchanger through four stents between them.

The thermal conduction power of three heat exchangers can be calculated using the following formulas:

$$3 \times 4 \times \frac{\Delta Q}{\Delta t} = 3 \times 4 \times kA\frac{\Delta T}{\Delta x} \approx 21.10\text{W} \tag{3}$$

where

k is the material's thermal conductivity,

A is the cross-sectional surface area,

ΔTis the temperature difference between the ends,

Δx is the distance between the ends,

In conclusion, the total thermal power of three heat exchangers and copper pipe can be calculated as:

$$Q_1 = 3 \times Q_{HE} + Q_{CT} + 3 \times 4 \times \frac{\Delta Q}{\Delta t} = 36.39\text{W} \tag{4}$$

3. Cooling test platform design

In order to meet the cooling requirements of RXC, a cooling test platform composed of cooling test circuit and its data acquisition system is developed. Devices in the cooling test platform need to be selected carefully according to the pressure of helium and the temperature of cooling water provided by ITER. The combination of gas cooling and water cooling is adopted in the design. Furthermore, a Data Acquisition (DAQ) system is designed based on Experimental Physics and Industrial Control System (EPICS) framework, which implemented functions for real-time data acquisition, temperature control, supervision and archiving [8].

3.1. Platform architecture

Cooling test platform is designed for RXC cooling test which requires helium and water as cooling medium. Considering constraints of helium in ITER, the closed-loop platform is adopted. Cooling test platform is mainly composed of one compressor which plays the role of pressed gas source, one water-cooled unit which provides cooling water and two water-cooled heat exchangers in which helium is cooled by water (as shown in Fig. 3). The heat generated in the experiment is carried away by helium which is recycled in closed loop. In addition, helium can be controlled by an electric valve from a tank for supplying when the pressure in cooling loop is lower than the set point. Helium can be recycled into the tank after experiment. For achieving control of the main circuit flow, an electric bypass valve is used. Meanwhile, heating equipment is used for temperature simulation.