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# NUMERICAL ASSESSMENT OF BEAM DIAGNOSTIC CALORIMETER FOR EAST NEUTRAL BEAM INJECTOR*

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*Abstract*

Neutral beam injection is one of the most effective means of plasma heating and has been also verified to be applicable for current driving. In order to support the physical research of EAST, two neutral beam injectors (NBI, 80keV, 4 MW) have been developed and constructed in Institute of Plasma Physics, CAS. In order to evaluate beam intensity distribution and divergence, a moveable sophisticated copper short-pulse beam diagnostic calorimeter is designed and installed on the NBI test stand. In this article, the structure of calorimeter, the operating parameters are introduced. The new diagnostic calorimeter plate bombarded by the beam adopts blocking design and there is no heat transfer between adjacent block. Thermocouples are installed into the block, so the temperature can be measured precisely. Based on the data obtained by thermocouples, the beam pattern can be plotted. In order to ensure the diagnostic calorimeter work safely, the operating parameters are explored using FEM. As a new beam diagnostic calorimeter, it solves the problem of mutual interference due to the heat transfer of each block, it can give more precise beam property comparing with the present calorimeter.

## INTRODUCTION

Neutral beam injection is one of the most effective means of plasma heating and has been also verified to be applicable for current driving[1-5]. In order to support the physical research of the Experiment Advanced Superconductive Tokomak (EAST), two identical neutral beam injectors (NBI, 80 keV, 4 MW) have been developed and constructed in Institute of Plasma Physics, Chinese Academy of Sciences [6-11]. In order to evaluate more precisely the beam intensity distribution, divergence and uniformity [12-16], a moveable sophisticated copper short-pulse beam diagnostic calorimeter is designed and installed on the NBI test stand. The new diagnostic calorimeter plate bombarded by the beam adopts blocking design and there is no heat transfer between adjacent block. Thermocouples are installed into the block, so the temperature can be measured precisely. Based on the data obtained by thermocouples, the beam pattern, divergence can be obtained. Considering the limitation of the heat exchange capacity, the diagnostics calorimeter only works in short-pulse mode, in order to determine the operation parameter, the diagnostics calorimeter is analyzed by FEM. In this article, the structure of calorimeter, the primary simulation results are introduced. Simulation results give the maximum operation pulse length at different beam energy.

As a new beam diagnostic calorimeter, it solves the problem of mutual interference due to the heat transfer of each block. Comparing with the present calorimeter, it can give more precise beam property.

## SIMULATION AND ANALYSIS

### *Layout and Design of Diagnostics Calorimeter*

Short-Pulse beam diagnostic calorimeter is installed between the gas baffle and bending magnet. Diagnostic calorimeter can be moved left and right under the traction of steel cable (see Fig.1). The diagnostic calorimeter will be moved out of beam channel during long pulse beam extraction.

The diagnostic calorimeter is designed to be operated inertially. It is made of a cooling back plate with a cooling circuit and 5×19 copper blocks which are brazed on the "beam side". Each block is inertially cooled via small cooling channels in the back plate and through a small ø10 mm×2 mm copper cylinder that acts as a thermal resistance between cooling plate and block. Each block has a surface of 30 mm×30 mm and a thickness of 25 mm. Each block is separated from adjacent blocks by a 2 mm gap (see Fig.2). With this solution the transversal heat transmission between blocks during the beam phase is practically negligible. 34 sheath thermocouples (K-Type) are used for temperature measure of the calorimeter (see Fig.3). The embedded thermocouples are positioned at half depth (12.5 mm) of a block (which is 25 mm thick) in order to provide a good assessment of the average block temperature. According to the temperature rise of the blocks, the beam profile in vertical and horizontal direction can be obtained.

### *FEM Analysis of Diagnostics Calorimeter*

The incidence angle of the beam on the calorimeter is supposed to be 90˚. The simulations have been performed with pulse length 1s, heat flux $10MW/m^2$ (uniform distribution). The flow rate of cooling water is 2m/s and the origin temperature is 293K. The thermal radiation between the adjacent blocks is ignored. The model is shown in Fig.4.

**Relationship between Inclination Angle and Surface Temperature of Block** In order to decrease thermal radiation between the adjacent blocks, the black is designed as regular hexahedron (see Fig.5a). For the difference of heat transfer path, there is a big gap between edge and center (see Figs.5b, 5c) with the change of inclination angle α. As the softening temperature of the material of

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diagnostics calorimeter (oxygen-free copper, OFC) is about 573K, the edge of block inevitably become priority concerned point. Figure 5d gives the relationship between the inclination angle and the temperature difference between edge and center. It can provide certain reference for designing head-loading components.

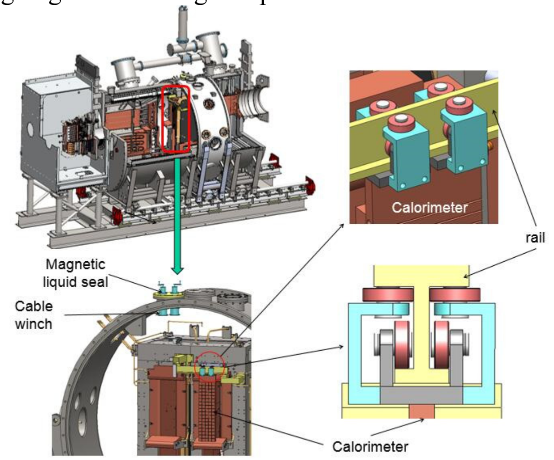


Figure 1: The layout of short-pulse diagnostics calorimeter.

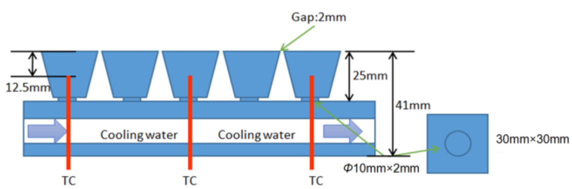


Figure 2: The design of short-pulse diagnostics calorimeter.

Figure.3: The installation of thermocouple in short-pulse diagnostics calorimeter.

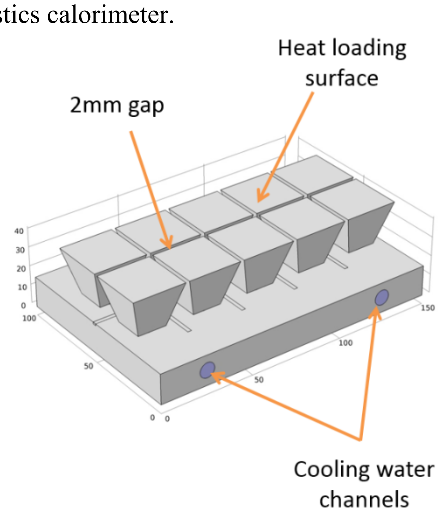


Figure 4: The model of FEM simulation for short-pulse diagnostics calorimeter.

**Three-dimention Temperature Distribution Varying with Time** The temperature of block is measured by the thermocouples embedded in it. The beam parameters, such as beam profile, divergence angle and uniformity and so on, can be calculated. Figure 6 gives the 3D simulation temperature distribution of diagnostic calorimeter at the end of beam extraction. It shows that there is a difference of more than 120 degree centigrade. In order to analyze the temperature change of the calorimeter during the beam extraction, the curves of temperature rise are plotted for the edge, center and the installation site of thermocouple (see Fig.7).

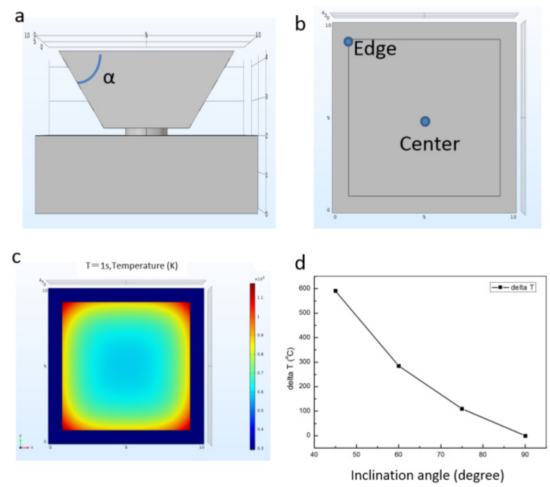


Figure 5: Inclination angle and surface temperature of a block: a. the section of block; b. the top view of block; c. the surface temperature distribution of black; d. relationship between inclination angle and surface temperature difference between edge and center.

**Three-dimention Temperature Distribution Varying with Time** The temperature of block is meausred by the thermocouples embedded in it. The beam parameters, such as beam profile, divergence angle and uniformity and so on, can be calculated. Figure 6 gives the 3D simulation temperature distribution of diagnostic calorimeter at the end of beam extraction. It shows that there is a difference of more than 120 degree centigrade. In order to analyze the temperature change of the calorimeter during the beam extraction, the curves of temperature rise are plotted for the edge, center and the installation site of thermocouple (see Fig.7).

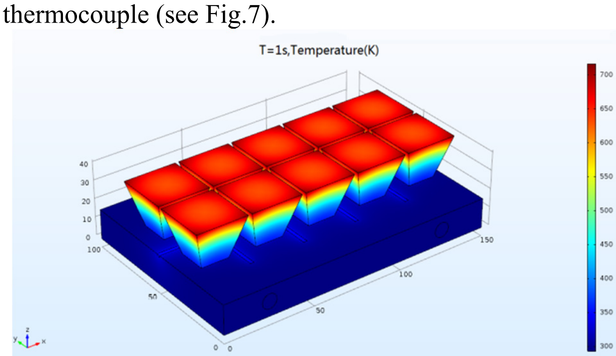


Figure 6: The 3D simulation temperature distribution of diagnostic calorimeter at the end of beam extraction.

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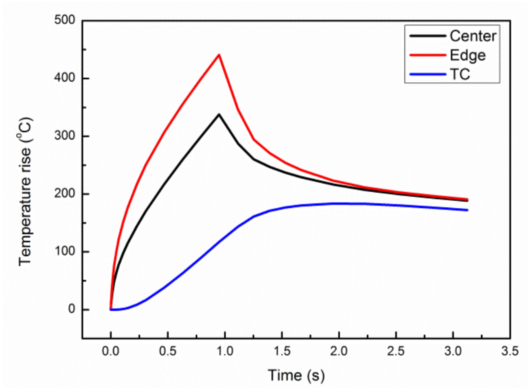

Figure 7: The curve of temperature rise varying with time.

**Operation Pulse Length of Calorimeter at Different Beam Energy.** The temperature rise of calorimeter is determined by the beam power density and pulse length. Fig.8 gives the beam average power density varying with beam energy at optimum perveance. Set the softening temperature of OFC 593K as safety threshold, the maximum operational pulse length is shown in Fig.9.

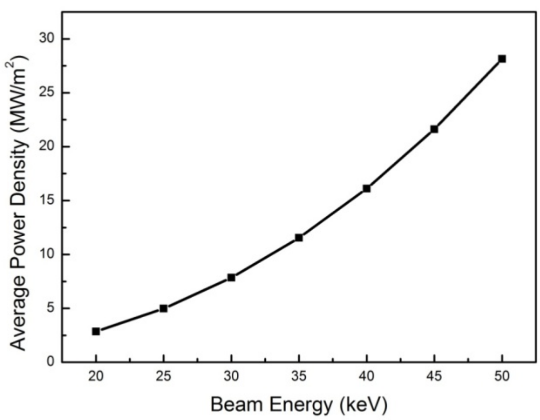

Figure 8: The beam average power density varying with beam energy.

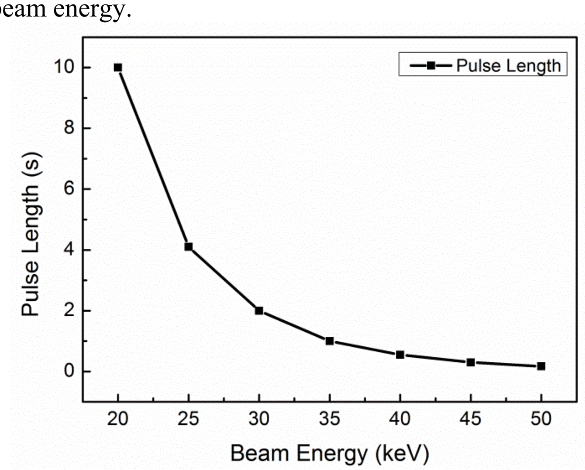

Figure 9: The maximum operational pulse length at different beam energy.

## CONCLUSION

Comparing with the current calorimeter, the new diagnostics calorimeter can provide up to 30mm high spatial resolution. Simulation results show that (1) the spatial resolution of calorimeter is determined by the scale of block; (2) the operational pulse length obvious decrease with the increase of beam energy. The application of new diagnostics calorimeter can provide more precise results of beam parameters and lay a foundation for optimization and development of ion source.

## REFERENCES

[1] C. Hu *et al.*, "Preliminary Results of Ion Beam Extraction Tests on EAST Neutral Beam Injector", *Plasma Sci. Technol.*, vol.14, no.10, p.871, Oct, 2012.

[2] A. Kojima *et al.*, "Progress in long-pulse production of powerful negative ion beams for JT-60SA and ITER", *Nucl. Fusion*, vol.55, no.6, p.063006, Jun, 2015.

[3] R. Maurizio *et al.*, "Characterisation of the properties of a negative hydrogen ion beam by several beam diagnostic techniques", *Nucl. Fusion*, vol.56, no.6, p.066012, Jun, 2016.

[4] C. Hu *et al.*, "Design of Neutral Beam-Line of EAST", *Plasma Sci. Technol.*, vol.13, no.5, p.541, Oct, 2011.

[5] B Wu *et al.*, "Neutral beam injection simulation of EAST", *Fusion Eng. Des.*, vol.86, no.6-8, p.947, Oct, 2011.

[6] C. Hu *et al.*, "Achievement of 100 s Long Pulse Neutral Beam Extraction in EAST Neutral Beam Injector", *Plasma Sci. Technol.*, vol.15, no.3, p.201, Mar, 2013.

[7] C. Hu *et al.*, "Overview of Development Status for EAST-NBI System", *Plasma Sci. Technol.*, vol.17, no.10, p.817, Oct, 2015.

[8] C. Hu *et al.*, "First Achievement of Plasma Heating for EAST Neutral Beam Injector", *Plasma Sci. Technol.*, vol.17, no.1, p.1, Jan, 2015.

[9] C. Hu *et al.*,"The Recent Development of the EAST Neutral Beam Injector", *Chinese Phys. Lett.*, vol.32, no.5, p.052901, May, 2015.

[10] C. Hu *et al.*, "Performance of positive ion based high power ion source of EAST neutral beam injector", *Rev. Sci. Instrum.*, vol.87, no.2, p.02B301, Feb, 2016.

[11] Y. Xie *et al.*, "Upgrade of accelerator of high current ion source for EAST neutral beam injector", *Fusion Eng. Des.*, vol.100, no.7, p.265, Jul, 2015.

[12] L. Yu *et al.*, "Temperature Measurement System of EAST Neutral Beam Injector", *J. Fusion Enger .*, vol. 34,no.2, p.245,Feb,2014.

[13] Y.Xu *et al.*, "A new method of rapid power measurement for MW-scale high-current particle beams", *Nucl. Instrum. Meth.* A, vol.795, p.196, Sep, 2015.

[14] Y. Xu *et al.*, "Progress of beam diagnosis system for EAST neutral beam injector", *Rev. Sci. Instrum .*, vol.87, no.2, p.02B934, Feb, 2016.

[15] R. Nocentini *et al.*, "Beam diagnostic tools for the negative hydrogen ion source test facility ELISE", *Fusion Eng. Des .*, vol.88, no.6-8,p.913,Jul,2013.

[16] C. Hu *et al.*, "Analysis of the Pipe Heat Loss of the Water Flow Calorimetry System in EAST Neutral Beam Injector", *Plasma Sci. Technol.*, vol.18, no.11, p.1139, Nov, 2016.