Study on Qualification for Cold Mass Support of ITER FEEDER CFT

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Abstract

Cold Mass Support (CMS) is a very important internal component of ITER Cryostat feedthrough (CFT), which acts as structure support who bears shear loads and sliding, as well as where heat load transfer from room temperature to 4.2K component. Base on the special functional requirements and importance, the design of CMS should be qualified before the real production used on ITER Feeder system.

In this paper, the qualification process of CMS was studied, three kinds of qualification tests were done on CMS mockup and prototype, include structural mechanical strength test, sliding pad qualification tests, and thermal conductance test. Every testing process was introduced in detail, such as the load distribution of mechanical test, the setup of test platform, special test equipment and methods, etc. Some important performance parameters were obtained, such as the maximum deformation under mechanical load, the friction coefficient and some key performances of the Diamond-Like Carbon (DLC) coating, temperature gradient of CMS during cryogenic test, and so on. All these testing results could prove that the design of the CMS was satisfactory, and the qualification was successful.

1. Introduction

As the lifeline of ITER (International Thermonuclear Experimental Reactor) magnet system, FEEDER system transfer the electric power, cryogenic coolant and instrumentation wires to the superconducting magnets and structures [1,2]. Cold Mass Support (CMS) is a very important internal component of ITER Cryostat feedthrough (CFT) (Fig.1). At first, CMS should transfer not only the gravity load but also the torque generated in the containment duct (CD) by vertical Lorentz-forces along the entire CFT. Secondly, CMS needs to isolate the heat conduction between external room temperature components and internal low temperature components, the heat load of CMS self should be controlled less than 15 W. At the same time, CMS has to experience relative sliding motion during operation, which can give the Feeder System sufficient flexibility to mitigate loads in the Feeder Structure after cool down and during operation.

Fig. 1 The CMS assembly model with cryostat feedthrough

As shown in Fig.2, CMS is mainly composed of 3 segments [3,4]: 1) The main body of CMS, laser welding by two 316L stainless steel plate and one 316LN stainless steel cylinder; 2) Thermal intercept assy, include copper braids and shield plate, connect to thermal shield to improve the thermal contact and enhance the cooling performance of the CMS; 3) The sliding pads, which provide sufficient flexibility to mitigate loads in the feeder structure after cool down and during operation.

Fig. 2 The CMS assembly model

So base on above design requirements of CMS, three main qualification tests should be done for CMS prototype, include structural mechanical strength test, sliding pad qualification test, and thermal conductance test [5].

2. Mechanical Load Test Performance For Cms

2.1 Mechanical test load distribution for CMS

Fig. 3 Set of real load condiction on CMS

Load to bear on CMS mainly involve of three aspects: weight of supported structure, displacement from feeder system, Lorentz force and bending moment from busbar. The real load condition under the device operation state is shown in Fig.3: the mechanical strength of the CMS at room temperature must be qualified by applying simultaneously a 50 kN downward axial compression, 20 kN force acting along the direction of the Containment Duct (CD), 10 kN transverse force and a bending moment of 5kNm, acting along the axis of the CD.

2. 2 Mechanical load test setup

As the real feeder system is very complex and fussy for this mechanical load test, a simplified test setup has been performed. As shown in Fig.4, a Containment Duct (CD) model and a rail base have been designed to facilitate the realization of the CMS loading application. The analysis results (showed in Fig.5) indicated that the strain intensity distribution on this mockup was very similar with real production.

Fig. 4. Configuration of tooling for CMS mechanical load test

Fig. 5 Strain intensity distribution comparison

In order to measure the strain and stress conditions of CMS, there were 90 strain and stress sensors distributed on the test mockup, as shown in Fig.6.

Fig. 6 Strain sensors distribution

2.3Mechanical test

Apply the load according to the Load Step (Fig.7) for CMS mechanical performance test, and the sample-loading process of structural mechanics performance test was completed after a total of 61 steps for two load cases (Fig.8).

1) During the testing process, maximum parallel deformation of the CMS was 0.18 mm between load and unload condition, and without any breaking.

2) When test loads were applied to the maximum load condition, the maximum transverse deformation at the center of the CD was 0.93 mm which was much lower than design requirement 2.0 mm. After the loads were relaxed totally, the maximum deformation was 0.03 mm which was less than design requirement 0.5 mm.

3) No cracks appeared on any weld seams of the post-test CMS.

3. Qualification Tests For Cms Sliding Pads

The CMS has to experience relative sliding motion during operation, which can give the Feeder System sufficient flexibility to mitigate loads in the Feeder Structure after cool down and during operation.

Base on the technical requirements, the friction coefficient of the in the sliding interfaces should be less than 0.2 to reduce the loads, and the wear-resistant ability must can meet the requirement that the sliding surfaces can take 30,000 cycles with small displacement(0~5 mm) and very low speed (7E-5 m/s).

The material of the sliding pads is Aluminium Bronze (QAl 9-2), the friction coefficient between Aluminium Bronze and stainless steel is about 0.35, so the solid lubricant coating was considered. MoS_2[6] and DLC (Diamond-Like Carbon) [7], these two kinds of solid lubricant coatings were chose to do the below qualification tests for CMS sliding pads.

3.1 Friction test

Fig. 9 Frictiontest results of DLC/MoS_2film

The Friction test was performed on UMT-2 Ball-Turntable Type Friction Wear Testing Machine with straight reciprocating motion20 mm each time and repeat 60000 times. The result shows that, there was almost no wear on DLC coating after the friction test of 1200 m distance, the average friction coefficient was 0.147. The MoS_2 film was worn out after the friction test of 1200 m distance, the maximum friction coefficient was 0.442, the average friction coefficient was 0.245. The test curves are shown in Fig.9, and it showed that the fluctuation of DLC test curve was less than MoS_2.

3.2 Scratch test

The Scratch test was performed on NST6-146 Scratch Tester. The test results indicated that during the process of continuous loading, the maximum mutation of friction force and friction coefficient appeared and the film failed. As shown in Fig.10, the film-substrate cohesion of DLC film was 262 mN, and the film-substrate cohesion of MoS_2 film was 80 mN.

Fig. 10 Scratch test results of DLC/MoS_2 film

3.3 Wear rate test

TALYSURF CCI 3D laser profilometer was used to test film thickness and wear scar topography. Test method for film thickness is to prepare on the test piece and form a step between coated area and uncoated area, and then measure the difference in height of the step to decide film thickness. The test result indicates that wear rate of DLC film was 4.02×10^{-6} $mm^3/(N\bullet m)$ (Fig.11), and wear rate of MoS_2 film was 9.91×10^{-6} mm3/(N• m).

Fig. 11 Wear scar topography and area of DLC film after friction of 1200 m

3.4 The hardness of the nanometer indentation test

Fig. 12 Hardness of the nanometer indentation test result of DLC film

NST2-121 Nano-indenter was applied to perform micro-hardness test of composite solid lubricating film. As shown in Fig.12, the hardness of the nanometer indentation of DLC film was about 20.1 GPa. And hardness value of nanometer indentation of MoS_2 film was about 6.2 GPa.

All these qualification tests results showed that the properties of DLC film were better than MoS_2 film, and it is appropriate for the lubrication and prolonging lifetime of the sliding parts in Feeder system.

4. Thermal Conductance Performance For Cms

There is a large temperature difference between two terminals of CMS during TOKMARK working condition one side was connect with Containment Duct which works at 10-20 K level, another side connect with Vaccum Duct which works at room temperature. In order to avoid excessive heat load of internal cryogenic components, the heat load of CMS should be less than 15 W during the CFT operation process. To perform the test under the environment similar with the real CFT operation condition, we combined CMS with CFT prototype together to do the cryogenic test (Fig.12).

Fig. 12 CFT cryogenic test process

4.1 Cryogenic test process

A liquid nitrogen (LN2) circuit was used to cool down the CFT thermal shield which functions as an 80 K thermal interceptor. When the establishment of steady thermal state was confirmed, supply 4.5 K supercritical helium with 5 Bar pressure to the coolant pipes to cool down the internal components. Use the flow controllers to adjust the mass flow rate gradually, and finally stabilized the mass flow rate and bring the temperature difference to a significant value to benefit reliable calculation of heat load.

4.2 Cryogenic test result

As shown in Fig.13 and Fig.14, although the experimental data was some different from the simulation analysis, it is not straightforward to figure out the heat load from CMS to inner cryogenic components by comparison with simulation. But from the comparison of temperature of CMS in Table 1, the temperature gradient of CMS was smaller than prediction. So it can be expected that the heat load by CMS was not more than prediction 15 W.

Table 1 Temperature comparison of CMS

	Temperature gradient of CMS far from VB	Temperature gradient of CMS near VB
Test results	110~123 K	105~114 K
Prediction	85~109 K	85~109 K

5. Conclusions

All the qualification tests of CMS have been done with good performances:

1) The mechanical load test results showed that the CMS mechanical property can meet design requirements;

2) The sliding pads qualification tests showed that the DLC film coating is very suitable for CMS sliding pads and it can make the sliding interface of CMS can meet all functional requirements of Feeder CFT system;

3) The heat load test showed that the thermal insulation performance of CMS was good enough to control the heat load of CMS can be less than 15 W during the CFT operation process.

The qualification process of CMS was very successful and already approved by ITER Organization. Some formal real CMSs had been integrated with CFT components which should be delivery to ITER.

Declarations

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Authors' contributions:

Xiaoshi Tang: Conceptualization, Methodology, Writing - Original Draft, Validation.

Chen Liu: Conceptualization, Methodology, Writing - Review & Editing,Validation.

Kun Lu: Investigation, Supervision, Project administration.

Fuxing Chen, Tianjun Zeng and Wei Zhou: Resources.

Xiaojun Ni, Jaromir Farek and Man Su: Analysis.

Acknowledgements: Have been defined in section "Acknowledgements" in this manuscript.

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Figures

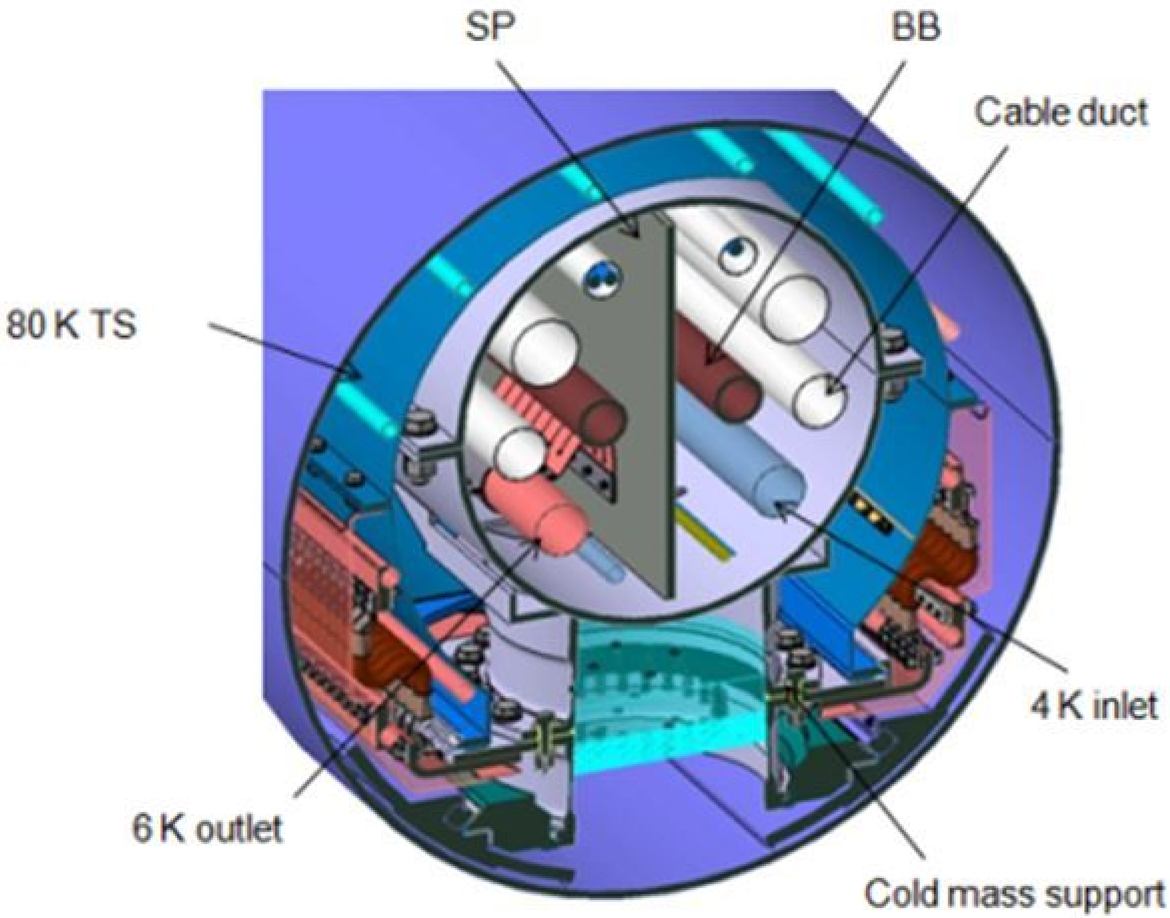


Figure 1

The CMS assembly model with cryostat feedthrough

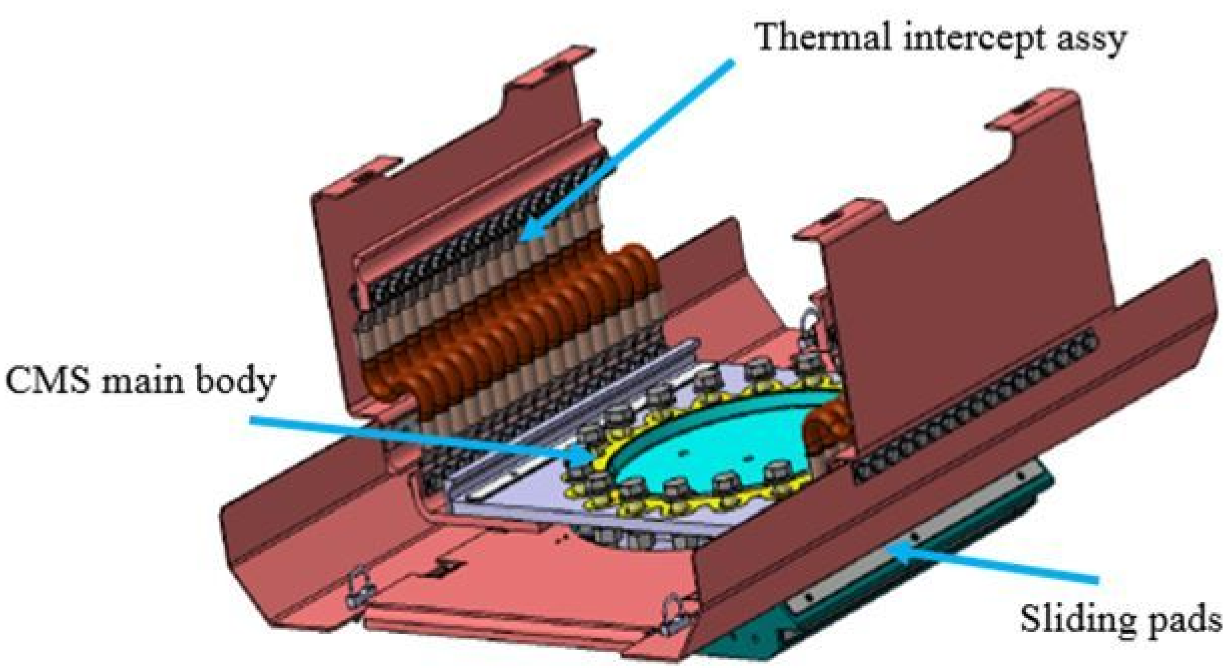


Figure 2

The CMS assembly model

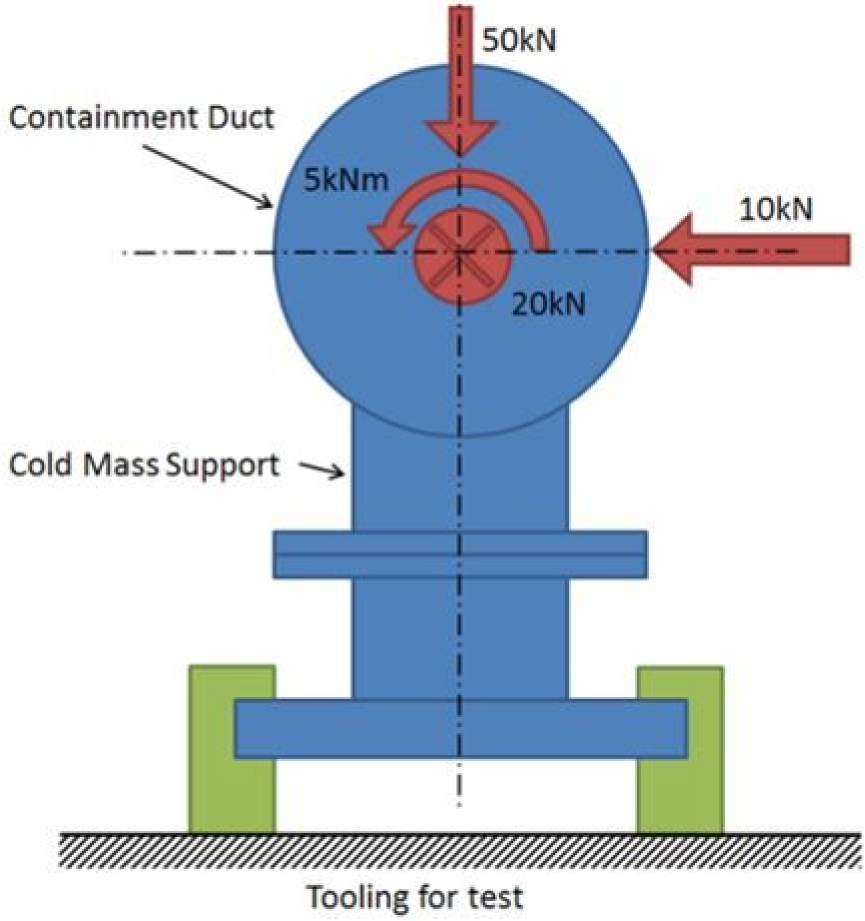


Figure 3

Set of real load condiction on CMS

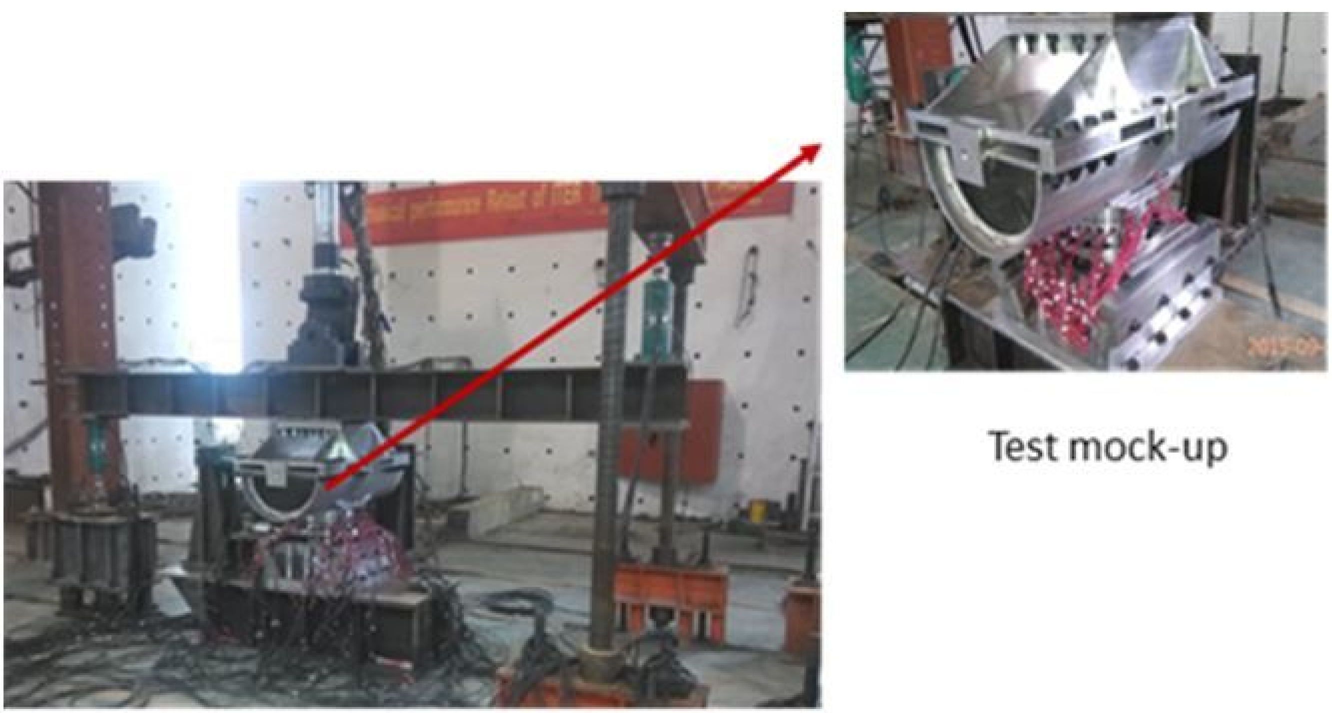


Figure 4

Configuration of tooling for CMS mechanical load test

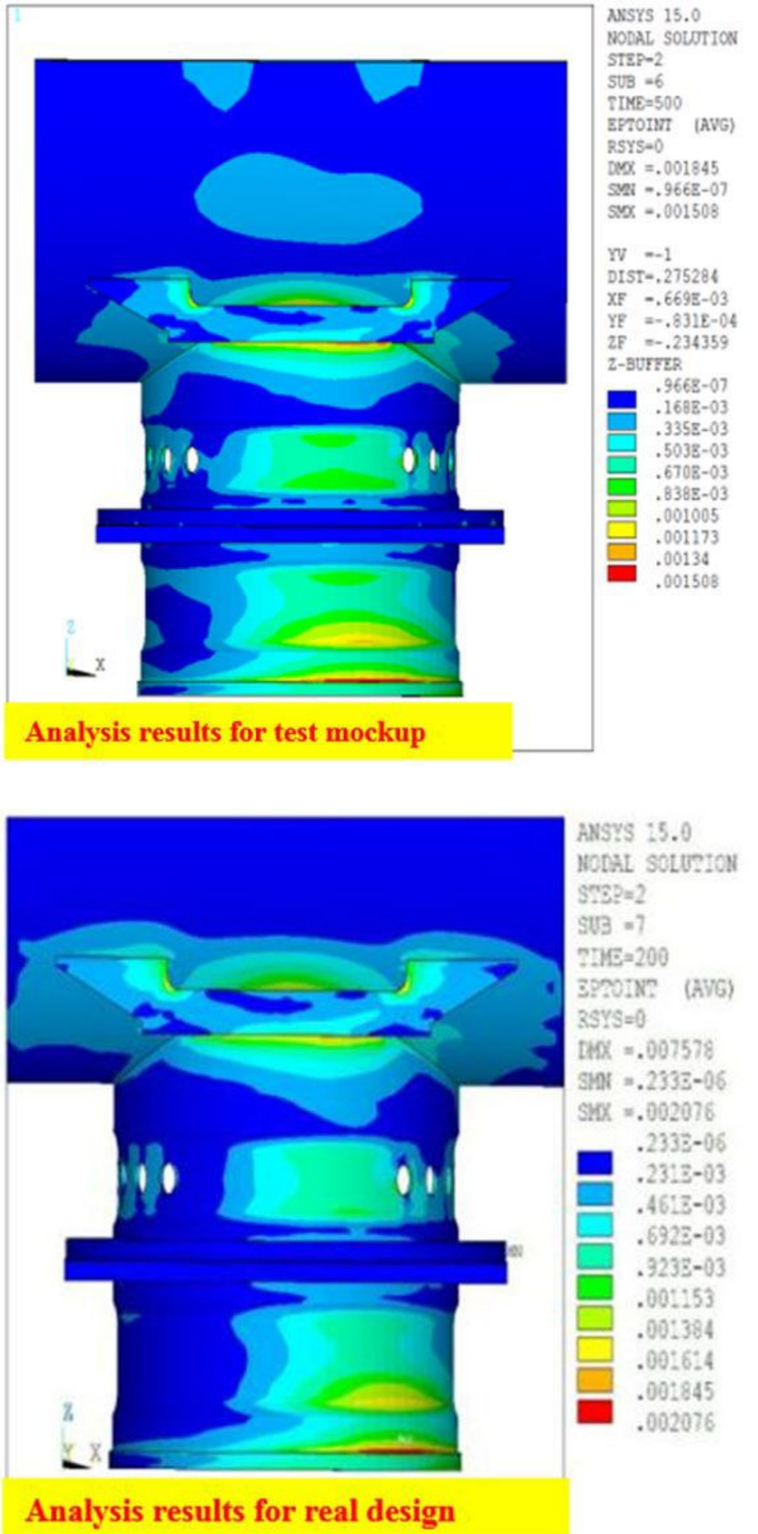


Figure 5

Strain intensity distribution comparison

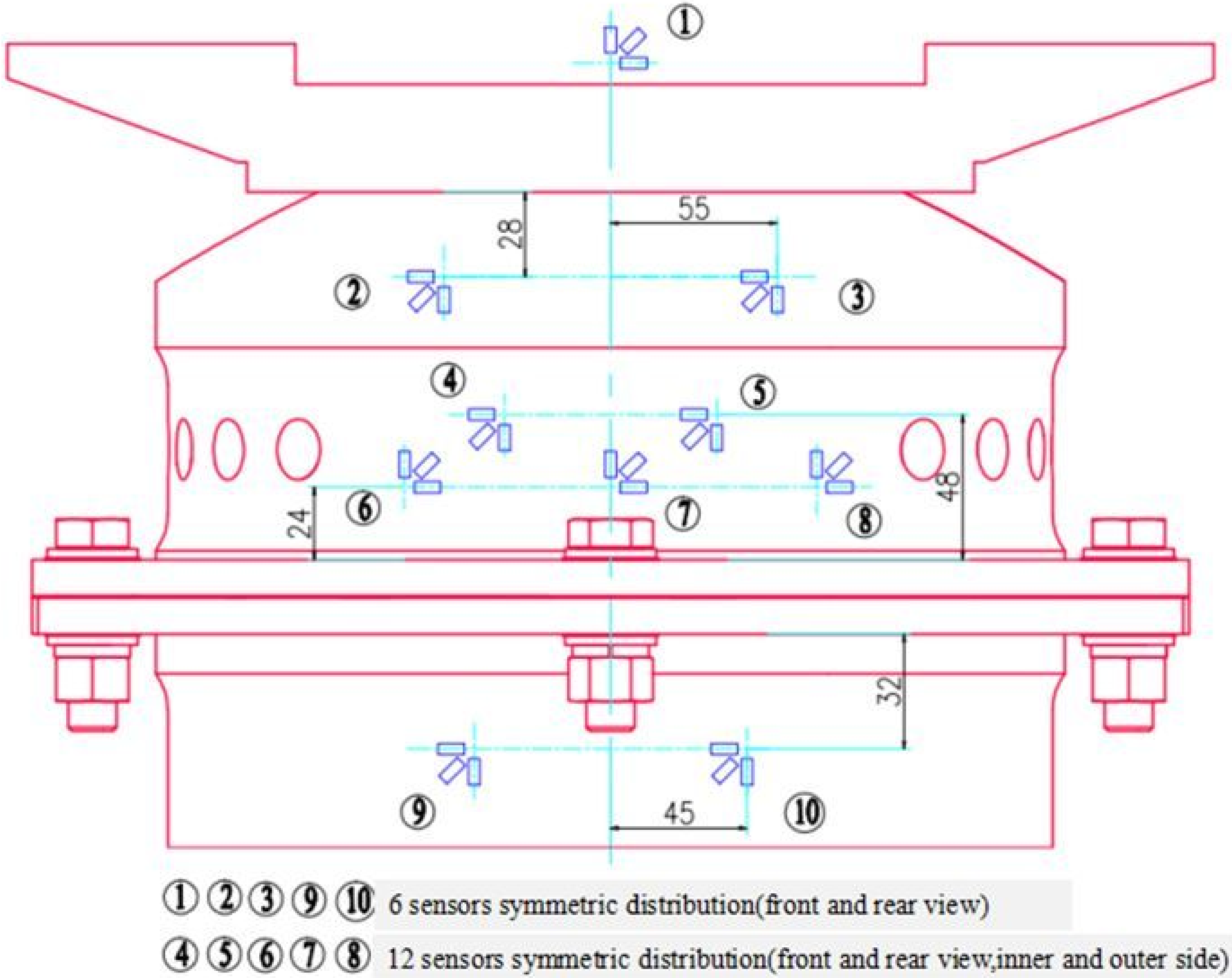


Figure 6

Strain sensors distribution

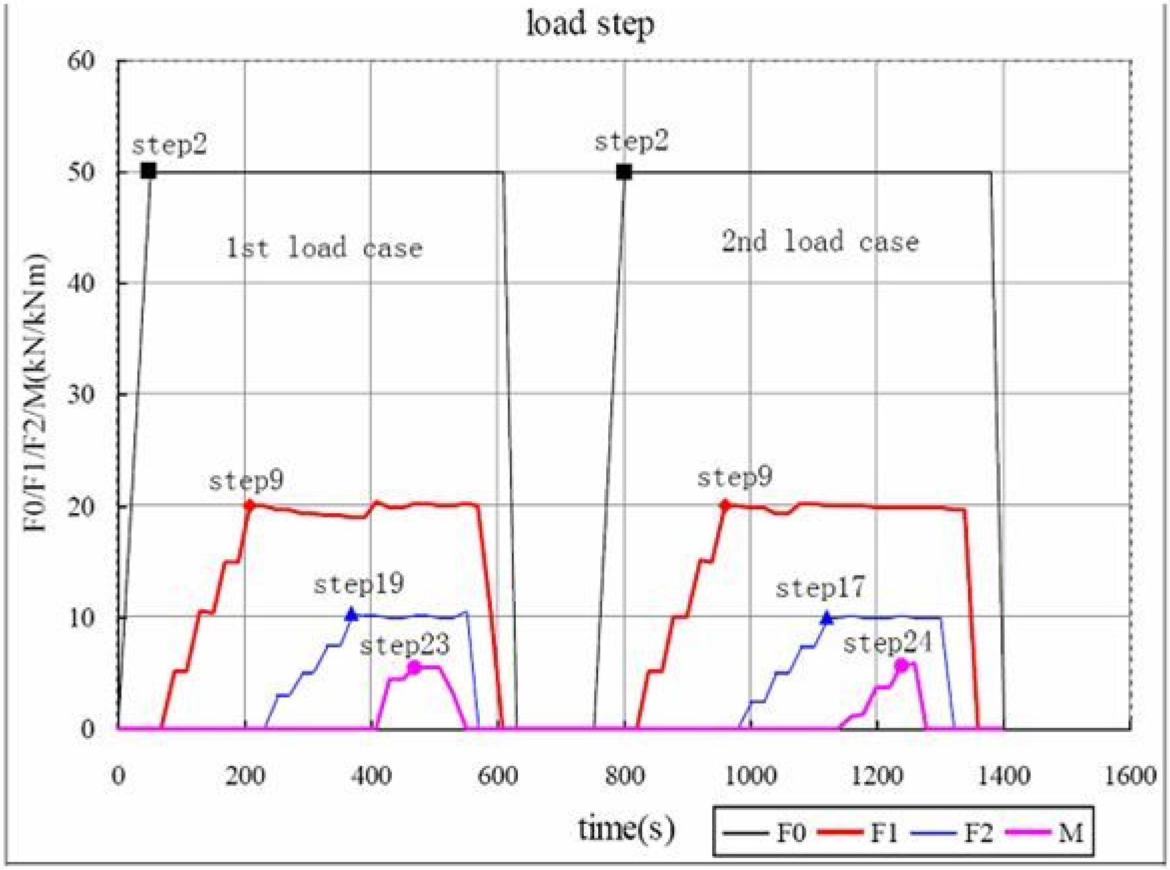


Figure 7

Real load distribution step for CMS

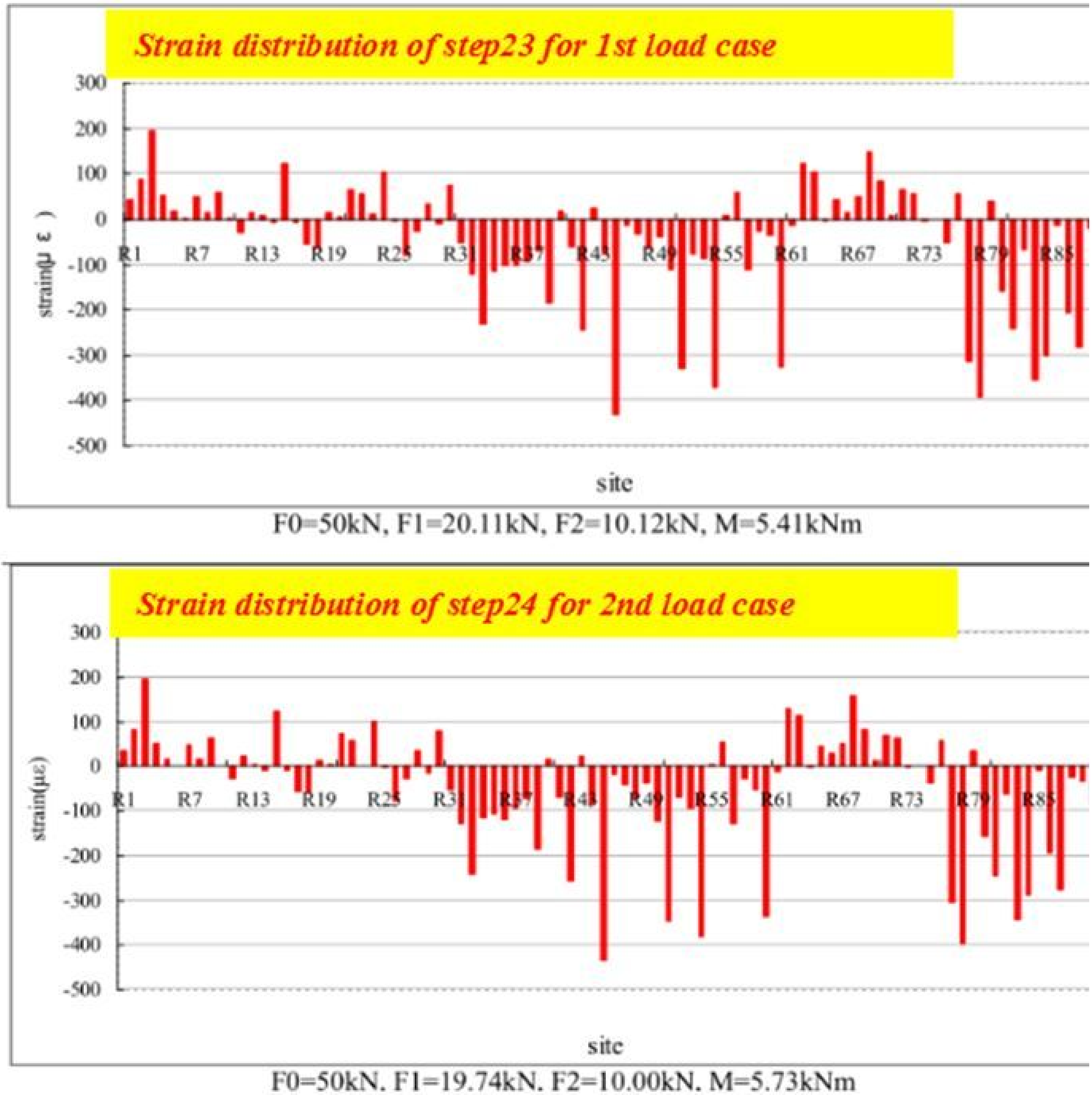


Figure 8

CMS mechanical test strain performance (two cases)

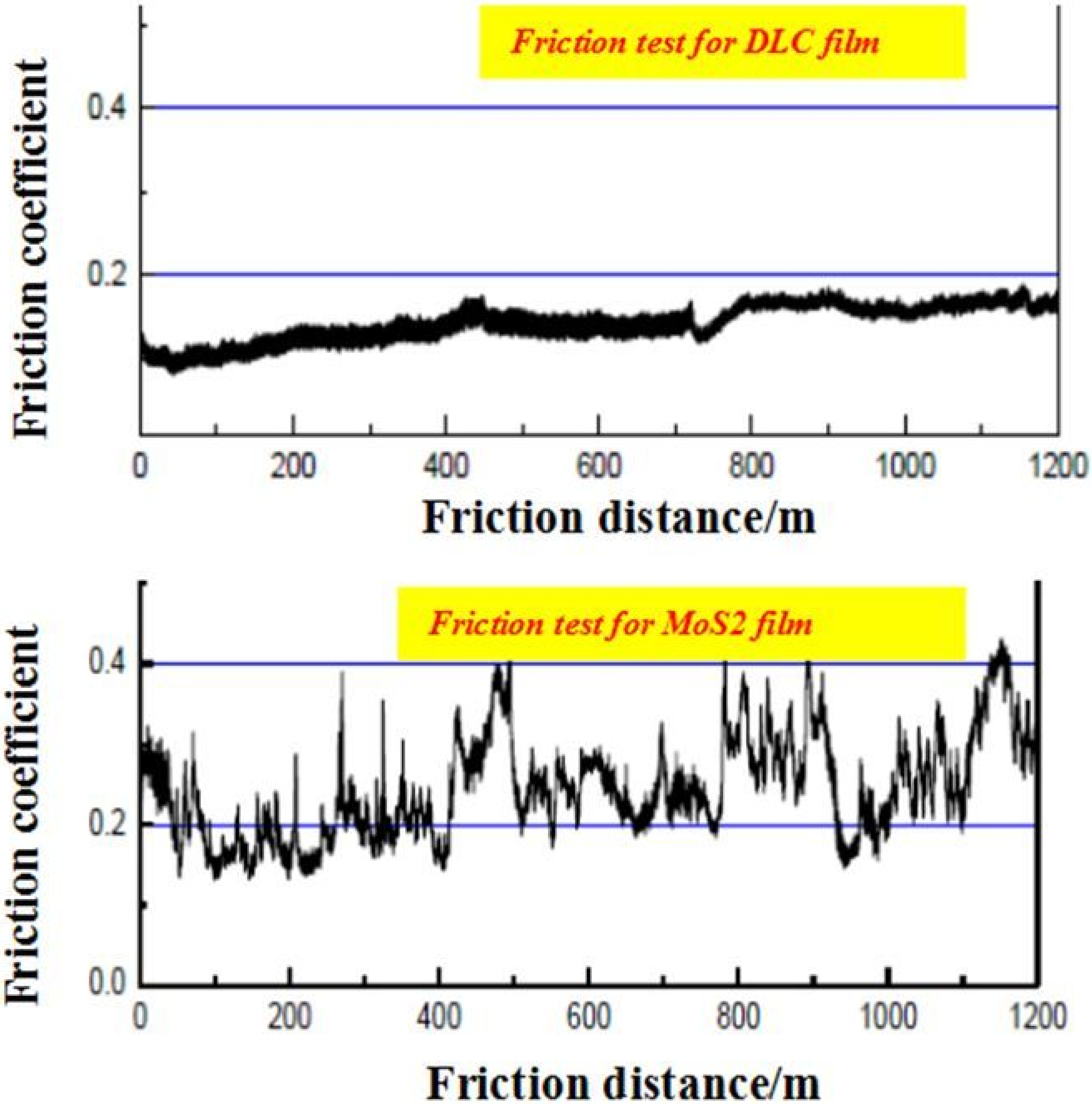


Figure 9

Frictiontest results of DLC/MoS2film

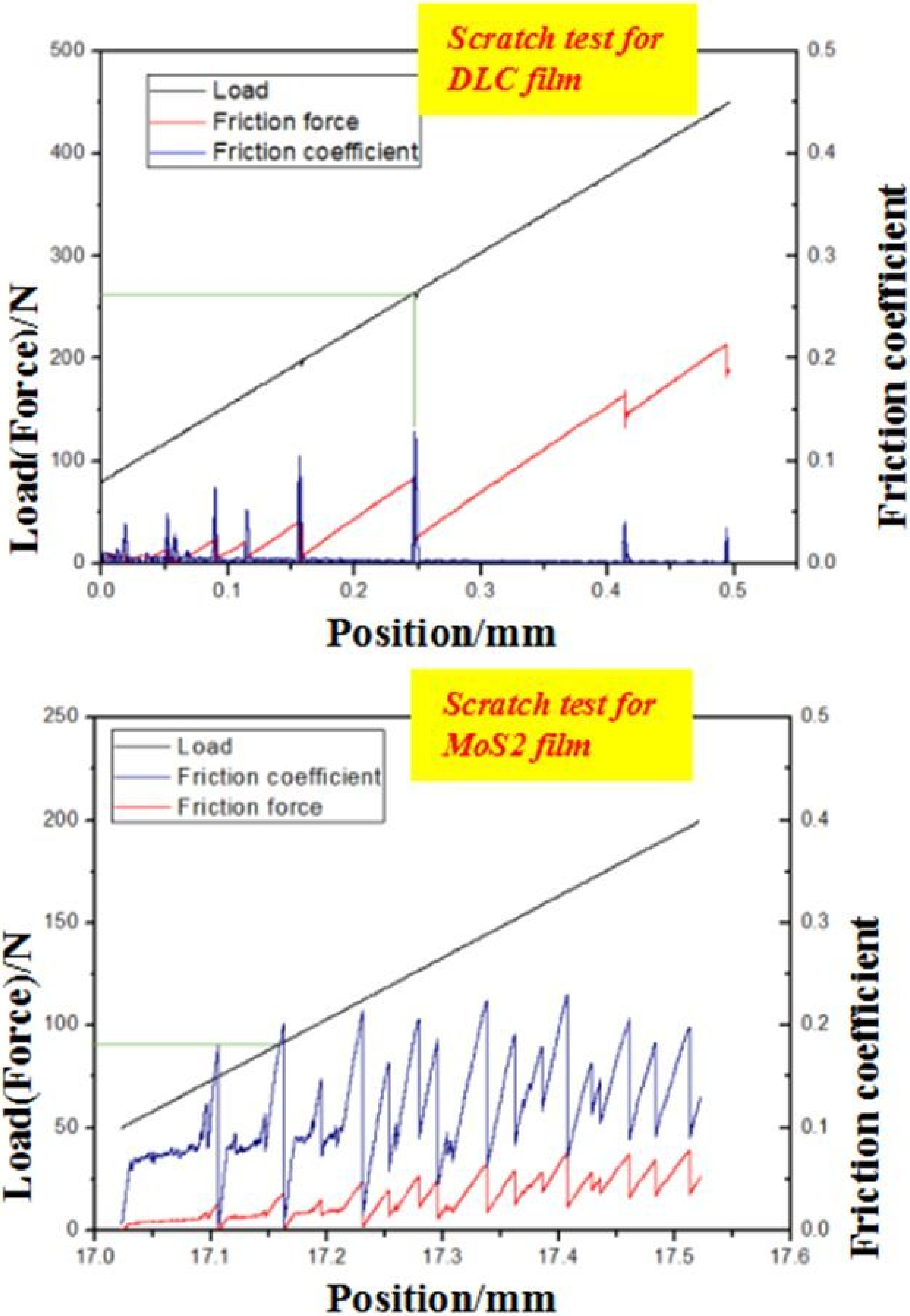


Figure 10

Scratch test results of DLC/MoS2 film

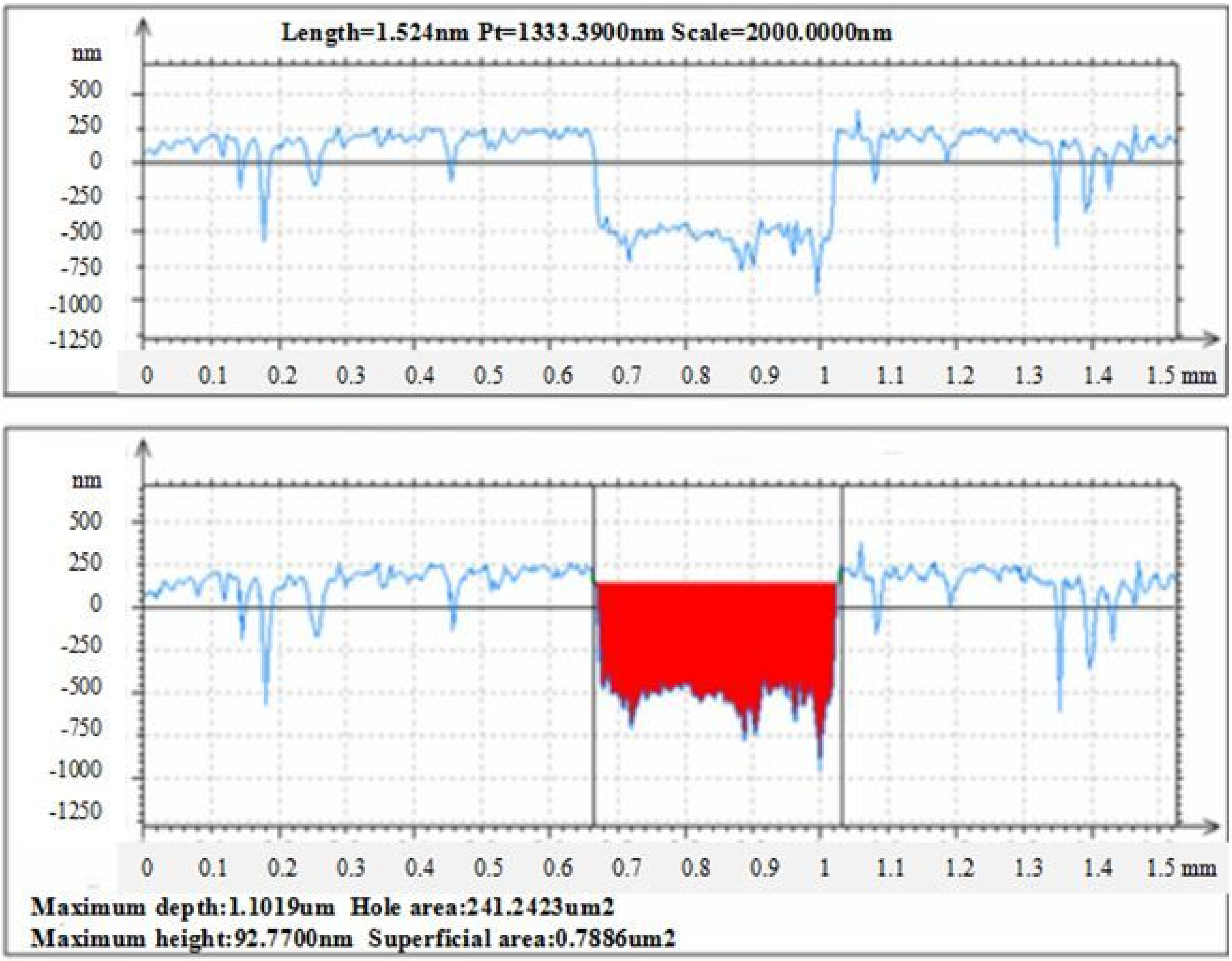
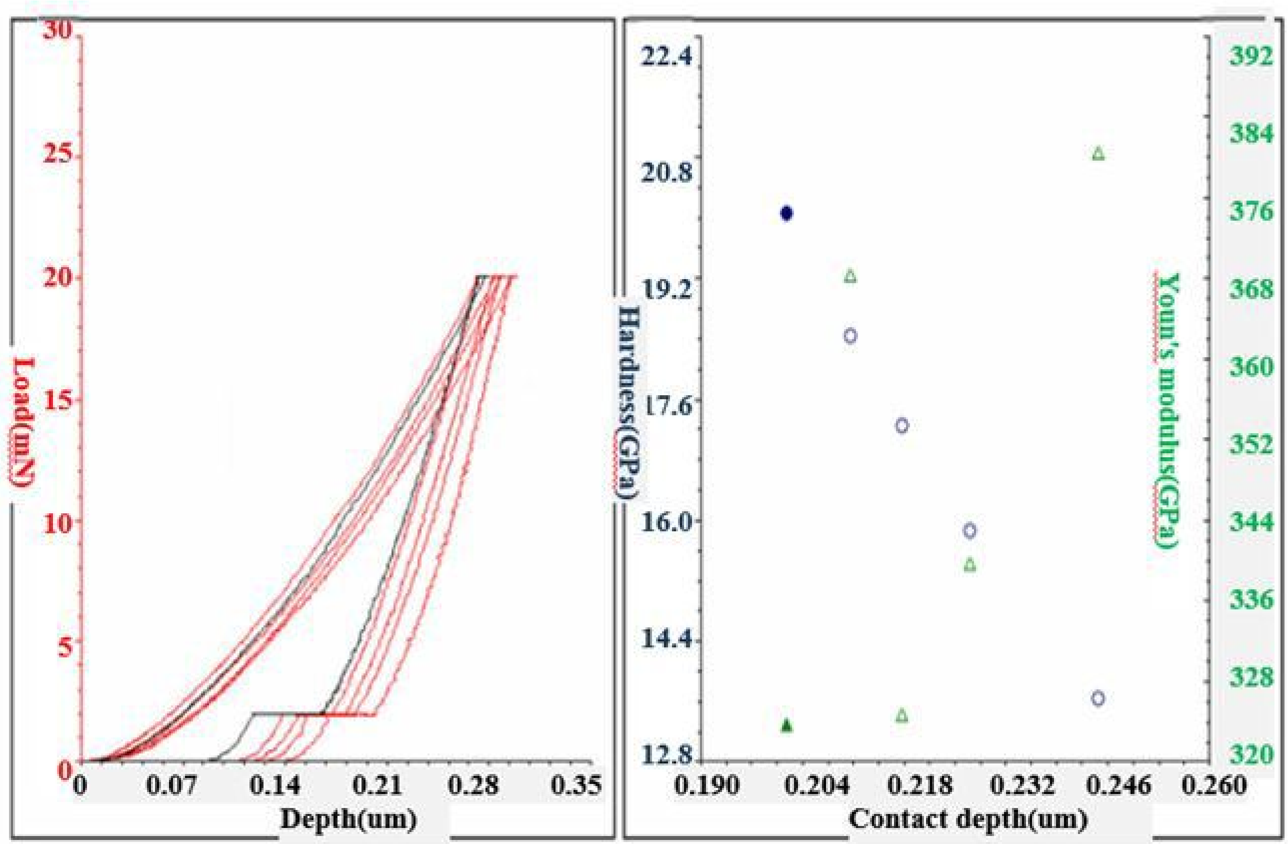


Figure 11

Wear scar topography and area of DLC film after friction of 1200 m



a. Loading-unloading curves

b. The hardness value of nanometer

Figure 12

Hardness of the nanometer indentation test result of DLC film. CFT cryogenic test process.

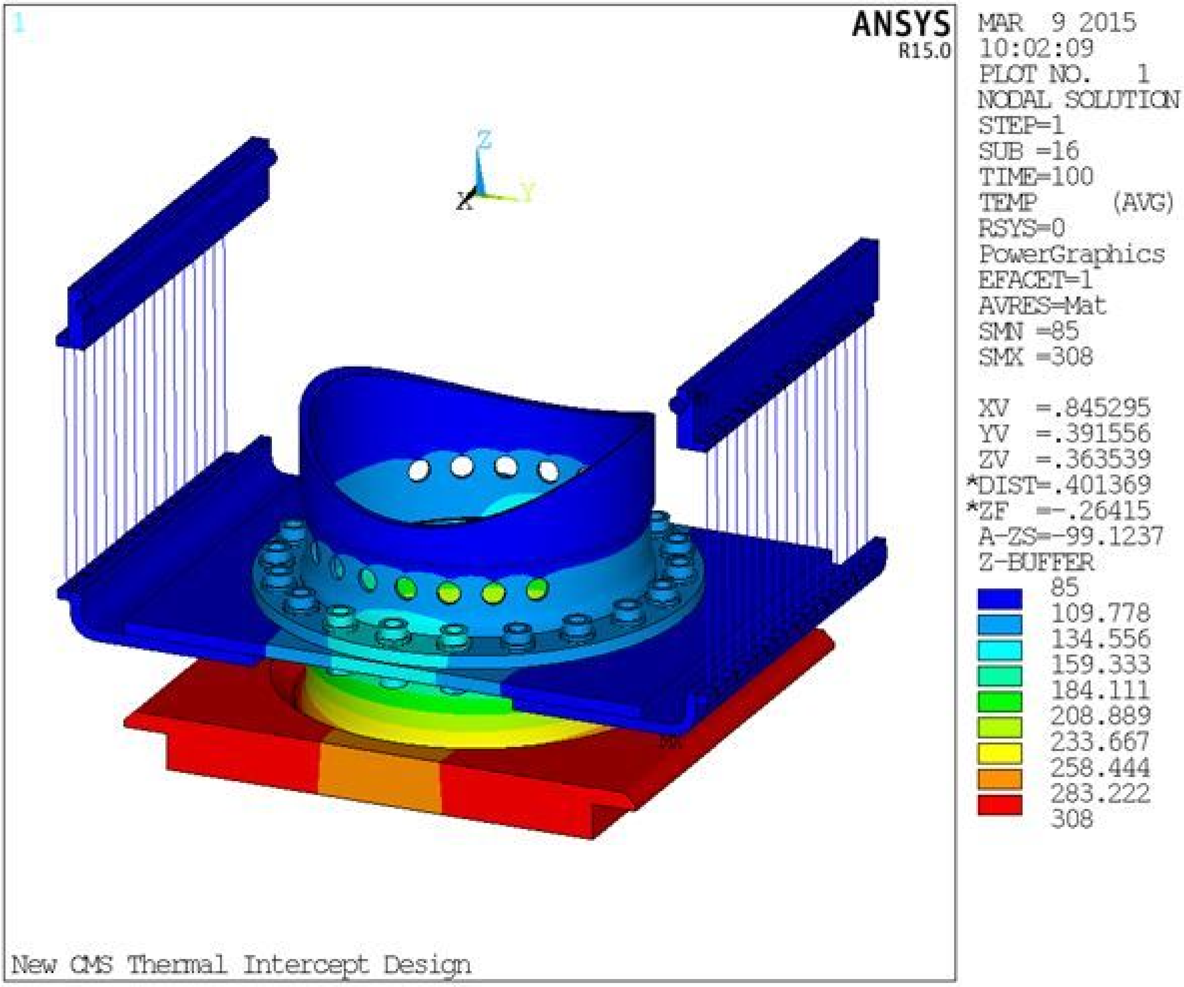


Figure 13

CMS temperature prediction

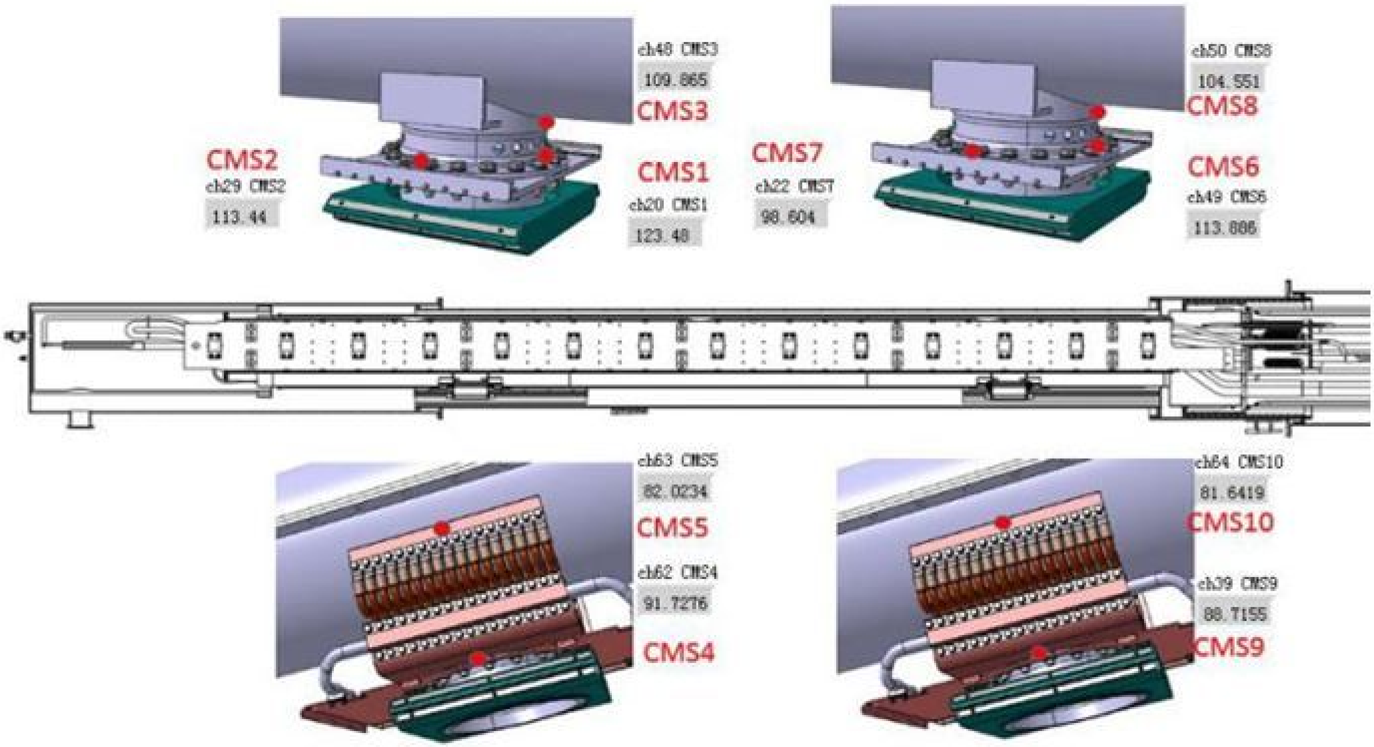


Figure 14

Temperature distribution of CMS for steady state