DESIGN VALIDATION OF ITER XRCS SURVEY SPECTROMETER WITH NUCLEAR CODE RCC-MR

SIDDHARTH KUMAR[1,A], SANJEEV VARSHNEY[1,2], SAPNA MISHRA[1,2], P.V SUBHASH[1,2], VINAY KUMAR[1,2]
GUIRAO JULIO[3], PHILIPPE BERNASCOLLE[5], MAXIM IVANTSIVSKIY[4], UDINTSEV VICTOR[3], ROBIN BARNSLEY[3], JOELLE ELBEZ-UZAN[3], MICHAEL WALSH[3]

[1]ITER-India, Institutes for Plasma Research, Bhat, Gandhinagar 382428, India
[2]Homi Bhabha National Institute, Anushaktinagar, Mumbai-400094, India
[3]ITER-Organization, Route de Vinon sur Verdon - CS 90046, 13067 St. Paul-Lez-Durance Cedex, France
[4]Budker Institute of Nuclear Physics, Novosibirsk, Novosibirskaya oblast', Russia, 630090
[5] Bertin Technologies, CS 30495, 13593 Aix en Provence Cedex 9, France
[a]email: siddharthk@iter-india.org

Abstract

In the ITER, systems are classified in the different safety categories as per their function in the machine; Protection Important Components (PIC) classified systems needs more attention during the design and analysis for better safety margins. The French Nuclear Code RCC-MR (2007) is employed in the design, analysis and the manufacturing, applicable to the ITER protection important mechanical components. It is always a challenge to the designers to develop and qualify the design for a PIC system under ITER loading conditions. This becomes even more stringent when the system is exposed to high nuclear radiation and performing the confinement function of radioactive tritium as in the case of XRCS Survey diagnostic system. XRCS Survey diagnostics is an ITER PIC system, located in Equatorial Port Plug (EPP)-11, will be used to monitor impurities in the highly ionized state and measure line emission from plasma in the X-ray range (0.1 to 10 nm) according to the ITER measurement requirement. This system is connected with the Port Plug flange, due to its specific nature and exposed to complex environments of neutron radiation, high heat flux, electromagnetic forces, etc. To ensure the structural integrity of XRCS Survey from the constant loading (P Type damage), repeated loading (S type damage); we have studied various loads and associated load responses. These loads are broadly categorized in the following three types i) ITER generic loads ii) accidental loads and iii) radiation loads. FEM (ANSYS) analysis has been performed and the design is validated using the French Nuclear Code RCC-MR (2007). The paper describes the results obtained from structural damage analysis of XRCS Survey system, and their compliance with relevant design rules given in the French Nuclear code RCC-MR validating the design

1. INTRODUCTION

PIC is a component, which is important for protecting the public interests like Personnel health, safety, and sanitation, to protect the nature and its surroundings. Structure, instruments, Plant systems, material, hardware or software available in nuclear facility and that implements a function required for the demonstration. XRCS Survey diagnostics structure is PIC as it is having a safety function.

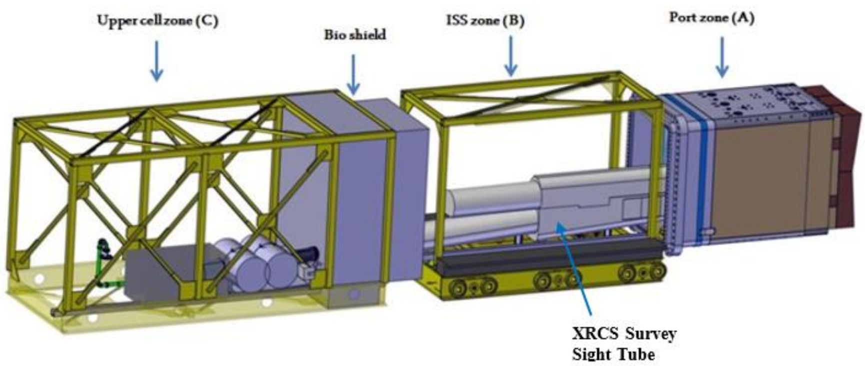

FIG. 1 *Integrated XRCS- Survey diagnostics in Equitorial Port Plug-11.*

The ITER XRCS-Survey diagnostic system [1,2] is a broadband (0.1 to 10 nm) X-ray crystal spectrometer for real time monitoring of absolute concentration and influx of plasma impurities by measuring X-ray line emission of highly ionized plasma impurities. The transport of X-ray emissions for detection is done using a nearly 10m long sight-tube, connecting the spectrometer to the closure plate of the port-plug, as shown in Fig. 1. The sight-tube is a nearly 5mm thick 160 mm diameter tube, made in sections, which are either welded or joined by flange connection. It is operated under ultra-high vacuum to minimize attenuation of low energy X-ray photons. Front of the tube is allowed to move with the vacuum vessel during baking and electro-magnetic (e-m) events by using a double walled bellow. Two double containment gate valves are mounted near bio-shield in the port-cell to isolate spectrometer from the torus vacuum. The full sight-tube is surrounded by neutron shielding, supported independently from ISS, to minimize activation of the nearby components, and hence bring down the shut-down dose rate to the safe level.

2. APPLICABILITY OF RCC-MR CODES

To ensure the structural integrity of XRCS Survey from the constant loading (P Type damage due to Excessive deformation, plastic instability, fracture), repeated loading (S type damage due to progressive deformation,); various loads and associated load responses have been studied and analyzed. These loads are broadly categorized in the following three types i) ITER Generic loads ii) Accidental loads and iii) Radiation loads. Finite Element Method (ANSYS) analysis has been performed and design is validated using the French Nuclear Code RCC-MR ed. 2007 [3].

The RCC-MR code is classified as the primary and non-primary stresses in total stress from elastic analysis, as shown in Fig.2. The total stress obtained by elastic analysis must also be broken down into various categories, as shown in Fig.3.

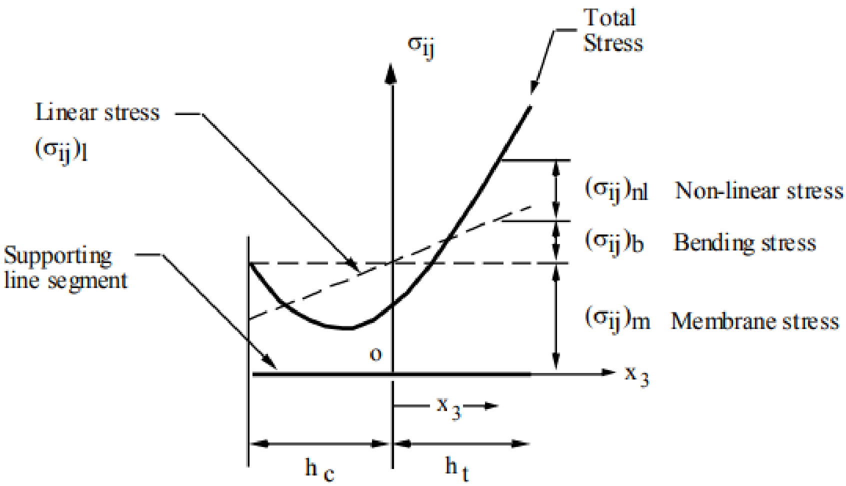

FIG. 2 *Classification of elastic stress [3].*

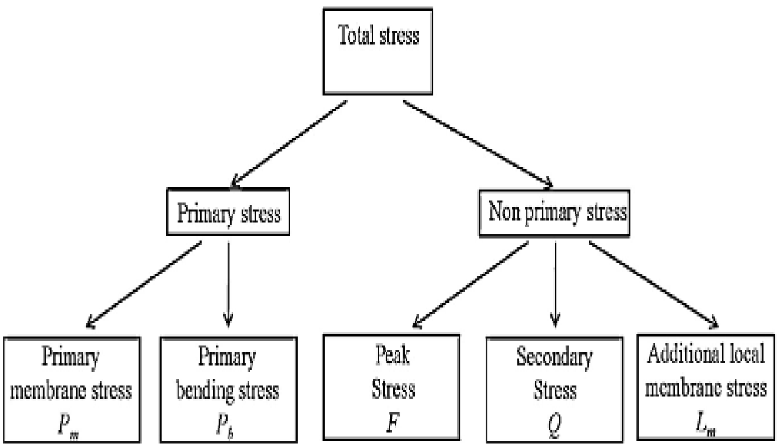

FIG. 3. *Categorization of elastic stresses[3].*

For validation of design, Elastic analyses carried out to ensure the structural integrity against undesirable deformation for P-type damages. Strain hardening has been used to study the Non-linear behavior of materials using kinematic hardening mathematical model for the prevention of S-type damages. Fatigue evaluation of all load conditions has been performed according to strain rate method in compliance with RCC-MR.

TABLE 1. FAILURE CRITERION IN RCC-MR.

Criteria	**Limit**
Protection against Plastic Collapse	$P_m \leq S$, $P_L \leq 1.5S$, $P_L + P_b \leq 1.5S$
Protection against Local Failure	$(\sigma 1+\sigma 2+\sigma 3) \leq 4S$
Protection against Ratcheting	$\Delta(P_L + P_b + Q) \leq 3S_m$
Protection against S type Damage, Ratcheting, Negligible Creep & Fatigue	$\Delta(P + Q) \leq 3S_m$

Analyses has been carried out for different load conditions to investigate the structural integrities and to increase the structural reliabilities of the XRCS-Survey, the several structural for various load conditions. Results are obtained from structural damage analysis of XRCS-Survey system and their compliance with relevant design rules given in the French Nuclear code RCC-MR validating the design has been done. Further, integrity assessment analysis of XRCS survey system is in progress with updated port integration and system concept.

3. MECHANICAL LOADING

Loads acting on the sight tube assembly of XRCS- Survey system are classified in to following type and are analyzed in view of ITER scenario:

A. Inertial Loads-These loads are due to self-weight and floor response during the earthquake scenarios.

B. Thermal baking load (THB) and Thermal operational loads (THO)

For baking of sight tube and other components heat provided on the sight tube, it will heat the components up to 240 °C. To avoid the local transient thermal stresses in the port plug, a heating rate of 5 °C/h is considered. After attaining 240 °C, that temperature is maintain up to 90 h then after cool down to 100 °C with cooling rate of 5 °C/h. After reaching 100 °C, system will be in normal operating condition

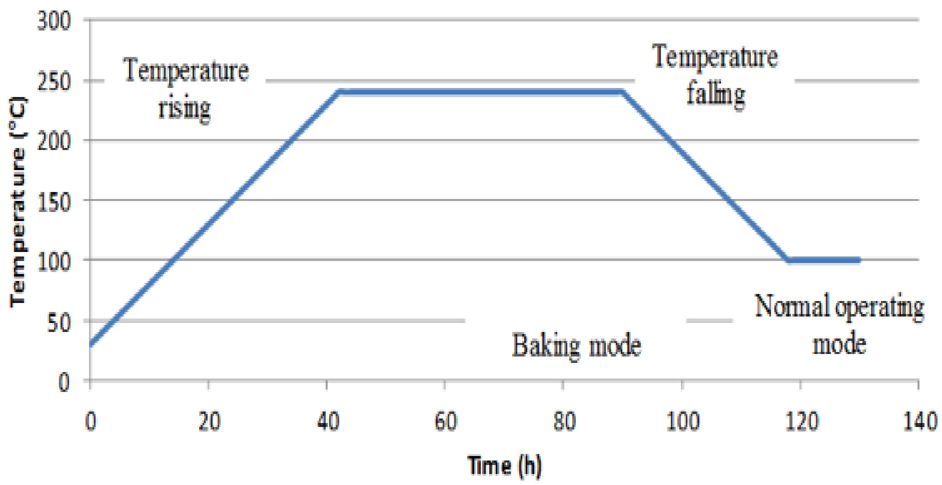

FIG. 4 *Thermal loads during baking and operation conditions on sight tube.*

C. Electro-Magnetic loads (EM)

To investigate electromagnetic forces & moments on XRCS Survey components during plasma disruption scenarios, Electromagnetic analysis is performed. To perform the EM analysis, a finalized global EM model was received from ITER organization with analysis input files for different plasma scenarios. To evaluate EM forces on XRCS Survey system, Survey system model was incorporated in global model. In this analysis, EM loads on whole XRCS structure are calculated for 5 different plasma disruption scenarios. Following are 5 plasma disruption scenarios that are analyzed on XRCS Survey system.

(1) MD_UP_Lin36ms (2) MD_UP_Exp16ms (3) MD_DW_Exp16ms
(4) MD_UP_Lin22ms (5) MD_DW_Lin22ms

D. Seismic Loads

Three applicable seismic levels loads Seismic Level 1 (SL-1), Séisme Maximal Historiquement Vraisemblable (SMHV) and Seismic Level 2 (SL-2) are analyzed for XRCS-Survey systems. If not combined with other loads, an SL-1 event is classified as a category II event (RCC-MR class A), an SMHV event is classified as a category III event (RCC-MR class C) and an SL-2 event is classified as a category IV event (RCC-MR class D). SL-2 events are most stringent loading condition and effects of these loads have been analyzed. Load spectrum on port plug rear flange has been generated form the ITER machine seismic analysis. Applicable spectrum loads are applied in X, Y and Z directions. Load spectra in X, Y and Z directions are presented in the Fig.5.

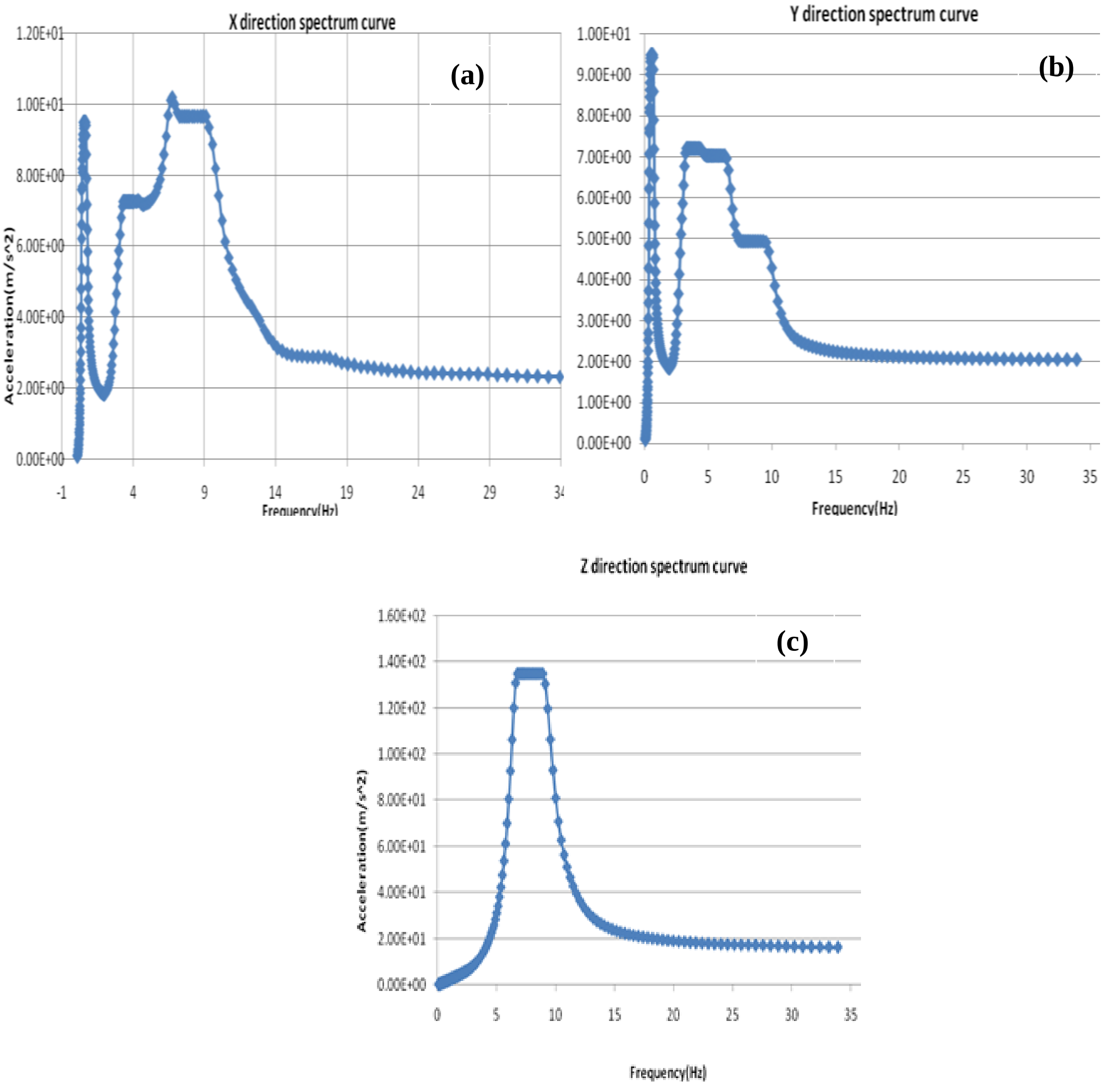

FIG. 5 *Load Spectrum (a)in X direction, (b) in Y direction, (c)in Z direction*

E. Pressure loads

These include coolant pressure (CP) during operation, and incidental internal and external pressure (In vessel ingress of coolant events (VV ICE), leakage in plasma chamber, and leakage in blanket feeding pipe in the equatorial port duct during LOCA PC III.

3.1 ITER LOAD COMBINATIONS FOR XRCS SURVEY

Further analysis is performed considering various combinations possible in ITER scenario with expected number of cycles. Following are different applicable load combinations for XRCS-Survey system. These load combinations are considered for design of XRCS Survey system and validate with RCC-MR code

TABLE 2. POSSIBLE LOAD COMBINATIONS

Mass	**Thermal**	**EM**	**Seismic**	**Accidental**	**Cat**	**No. of cycles**
DW	THO				I	30000
DW	THB				I	500
DW	THO	Worst EM			I	2600
DW	THO	Worst EM		VV ICE II	II	700
DW	TH B		SL-1		II	5
DW	THO	Worst EM	SL-1		II	5
DW	THO			VV ICE III	III	1
DW	THB			LOCA PC III	III	1
DW	THO		SMHV		III	1
DW	THB		SMHV		III	1
DW	THO	Worst EM		VV ICE IV	IV	1
DW	THO		SL-2		IV	1
DW	THB		SL-2		IV	1
DW	THO	Worst EM	SL-1		IV	1

4. FINITE ELEMENT MODEL DESCRIPTION

Three different analysis models are prepared for Thermal analysis and Structural integrity assessment. Among these models, two models are used for thermal analysis of XRCS Survey Sight-Tube system; one with-out Neutron shielding and one with neutron shielding to see the thermal effect of shielding on XRCS Survey Sight-Tube system as shown in Fig. 6 (a) & (b) respectively. While the third model is developed for structural integrity assessment, which consists of closure plate, Sight-Tube and primary vacuum boundary (First Gate valve) as shown in Fig. 6 (c). A finite element model of the CATIA geometry was created in ANSYS that was suitable for addressing the multi physics environment.

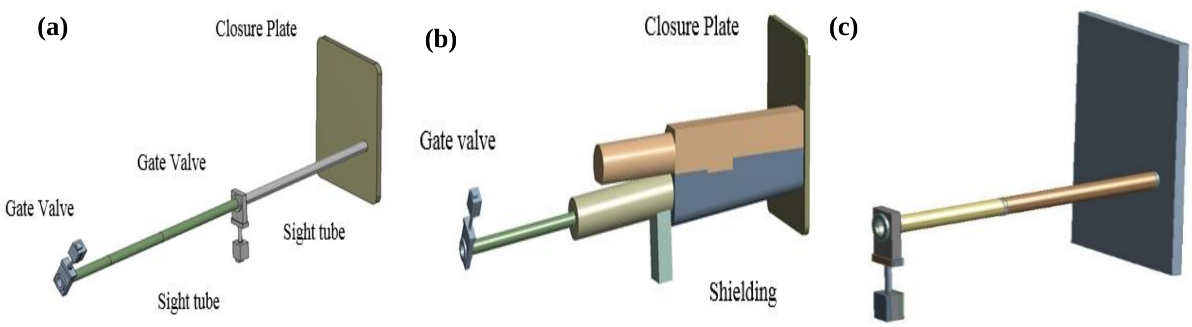

FIG. 6 *Finite Element Analysis Models (a) Thermal Model Without Shielding (b) Thermal Model With Shielding (c)Structural Integrity Model.*

5. RESULTS

5.1 EM ANALYSIS

A separate Electromagnetic analysis is performed on XRCS Survey Sight-Tube system for all the disruption scenarios mentioned in Loads and Boundary conditions section. In electromagnetic analysis electromagnetic force and moments are calculated on XRCS Survey Sight-Tube system. Results of electromagnetic analysis are summarized in Fig.7. From results we observe that, among all the disruption scenarios, MD_Up_Lin36 ms & MD_Up_Exp16ms case found to exert highest force and moment on XRCS Survey Sight-Tube system. As these forces and moment are not significant so the effects will be only analyzed with other load combinations.

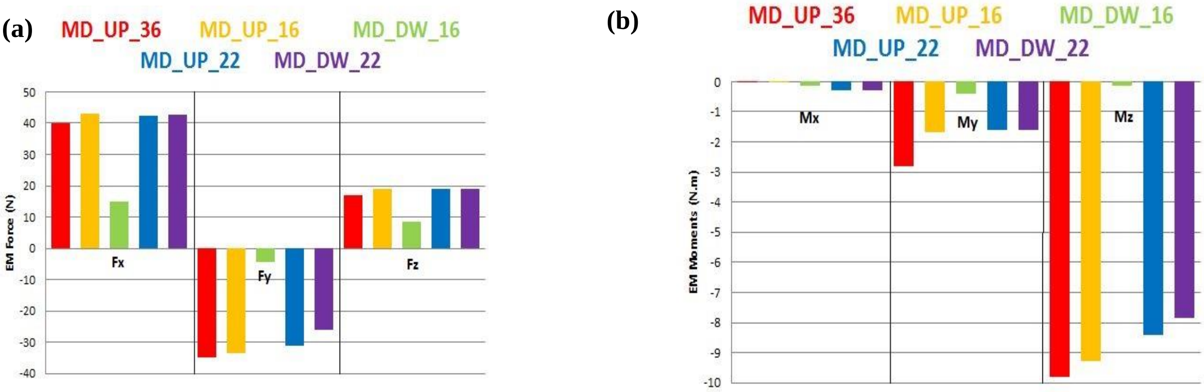

FIG. 7 Electromagnetic analysis (a) Forces in N (b) Moments in N-M.

5.2 THERMAL ANALYSIS RESULTS

Thermal analysis results indicate that baking of sight tube till 1m away from second gate valve will not affect the temperature of spectrometer temperature. It also shows that temperature of shielding will remain below acceptable limit for shielding Fig-8.

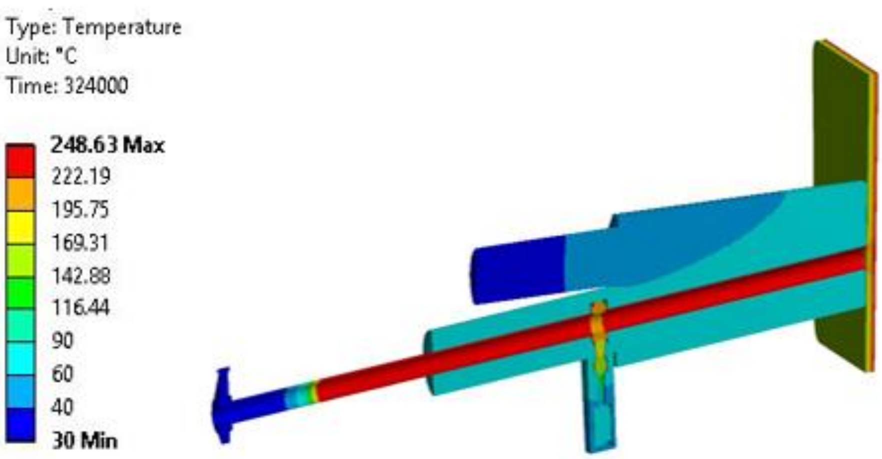

FIG. 8 *Temperature Profile on XRCS Survey Sight Tube*.

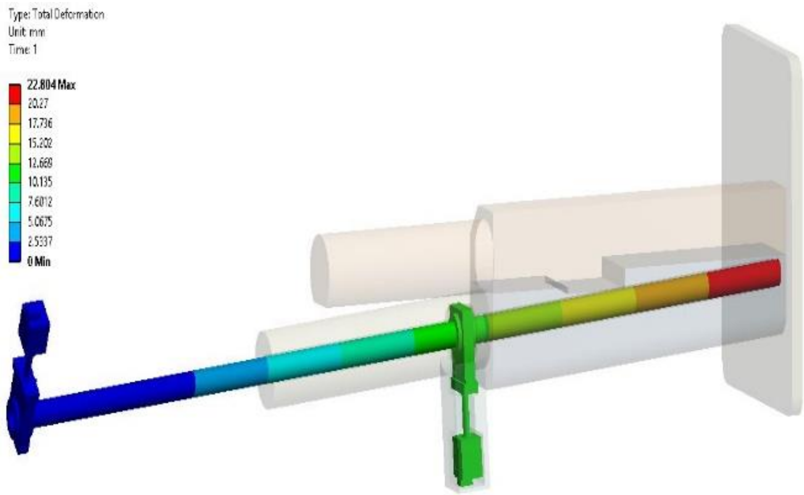

FIG. 9 *Deformation in XRCS Survey-Sight tube during Baking conditions*

Deformation due to thermal load during baking mode is shown in Fig.9. It is observed that maximum deformation in sight line components due to thermal baking condition will be in the range of 23 mm. This deformation is within the safe range but a double wall bellow will be used as a moment compensation for this deformation.

5.3 STRUCTURAL INTEGRITY RESULT

To ensure the structural integrity of XRCS Survey system for P-type and S-type structural damages using RCC-MR codes, analysis has been performed for the below mentioned load combinations shown in table-3. This analysis validated with criteria and compliance for different event category and damage type. Elastic analysis and Elasto-plastic analysis performed for the assessment of stress, strain, and displacement. These results further compared with the allowable limits recommended for the XRCS-Survey.

TABLE 3 LOAD COMBINATIONS FOR STRUCTURAL INTEGRITY ASSESSMENT

Load case No	**Load Combination**
1	DW+THB
2	DW+EM
3	DW+EM+SL-2
4	DW+EM+LOCA PC III
5	DW+EM+VV ICE IV

5.3.1 P-TYPE DAMAGE ASSESSMENT

For P-type damage assessment, linear elastic analyses has been carried out for different loading conditions and stress results were evaluated to check for RCC-MR compliance. Load case combining the following loads (DW+EM+VV ICE IV) found as worst case and maximum stress results were found. Maximum stress value of 142 MPa resulted in this load combination. Which completely satisfies the RCC-MR P-type damage criteria

5.3.2 S-TYPE DAMAGE ASSESSMENT

S-type damage has been assessed by performing elasto-plastic analysis for level A cyclic loading, the strain range evaluated for each cycle. It is used in load application to fatigue assessment, the equivalent stress (or strain), which is applying to input of fatigue curve [3].

5.3.3 RATCHETING ASSESSMENT

Applicable four load combinations evaluated for Ratcheting Assessment as shown in Table 4. The safety margin calculated for each load case for compliance with RCC-MR Ratcheting damage limit.

TABLE 4 COMPARISION WITH RCC-MR DAMAGE LIMIT

Load combination No.	Operating condition	Initializing event	Concatenated Events	RCC-MR Damage limit	Prevention against Damage	Safety Margin
1	DW, THO			(PM/L+PB+ΔQ) ≤ 3Sm	S type Damage Ratcheting	SM >86.20%
2	DW, THB			(PM/L+PB+ΔQ) ≤ 3Sm	S type Damage Ratcheting	SM >71.97%
3	DW, THO	Worst EM		(PM/L+PB+ΔQ) ≤ 3Sm	S type Damage Ratcheting	SM >86.21%
4	DW, THO	Worst EM	VV ICE II	(PM/L+PB+ΔQ) ≤ 3Sm	S type Damage Ratcheting	SM >86.20%

6. SUMMARY

1. Effect of different loads and load combination on XRCS Survey system has been analyzed using Finite element analysis method and validated using RCC-MR design codes criterion. Load case combining the following loads (DW+EM+VV ICE IV) found as worst case and maximum stress results are up-to 142Mpa. Maximum stress is found in safe range as per RCC-MR codes

2. Stresses and displacements caused by Thermal loads acting on the sight tube will the affect the temperature of Spectrometer assembly. Deformation of 23 mm has been assessed, it is also under the allowable limit. This deformation is input for double wall bellow design, used as a moment compensator for XRCS-Survey Sight tube.

3. Structural Integrity of ITER XRCS- Survey is being analyzed using RCC-MR recommendations, considering ITER load combinations. In this study P, type and S, type damage assessed and it is found that the XRCS Survey design is under the allowable safety margins.

Expressed views and opinions herein do not necessarily reflect those of the ITER Organization.

ACKNOWLEDGEMENT

Support from Common Port Plug Engineering Team, ITER organization

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