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Mechanical Monitoring Issues in Preparation to Next Step of W7-X Operation

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Mechanical Monitoring Issues in Preparation to Next Step of Wendelstein 7-X Operation

V. Bykov, A. Carls, J. Zhu, P. van Eeten, L. Wegener, H-S. Bosch and W7-X team

***Abstract*— The largest modular stellarator Wendelstein 7-X (W7-X) has successfully passed first phase of operation in Greifswald, Germany. The sophisticated W7-X superconducting magnet system with its non-linear support system has been carefully monitored using an extensive set of mechanical and temperature sensors. The paper focuses on detail consideration of cyclic magnet system behavior during operation with limiter configurations of plasma. Measurement results are carefully compared with predictions from updated numerical models and critical issues are highlighted. As a result, the structural monitoring tool is extended to follow enhanced requirements and expectations. The work is a preparation for upcoming more demanding phases with longer plasma pulses to guarantee safe and reliable W7-X operation with different divertor and scraper element configurations. The procedure to establish required sensor configurations, to analyze and to release new plasma regimes being compatible with W7-X component design values is also described.**

***Index Terms*— Wendelstein 7-X (W7-X), stellarator, structural monitoring, numerical FE analysis**

I. INTRODUCTION AND MOTIVATION

THE largest modular stellarator Wendelstein 7-X (W7-X) has successfully entered commissioning process before next phase of operation (OP1.2a) in Greifswald, Germany. The first phase (OP1.1) with limiter configurations of plasma with 2.5 T of magnetic induction on the plasma axis met successfully all project team goals. About 940 discharge programs have been done with maximum pulse length up to 6 seconds and with maximum input energy of 4 MJ. Besides main physical achievements (e.g. [1], [2] and [3]) it is necessary to mention that considerable generated structural loads (MN) in the W7-X systems were successfully endured.

Five-fold symmetric magnet system (MS) comprises 50 non-planar (NPC) and 20 planar (PLC) superconducting coils. In addition to the superconducting coils a set of 5 normal conducting trim coils could be in operation to allow a fine tuning of the main magnetic field. The magnet system has to provide a wide range of different magnetic field configurations already during coming operation phase (see Fig. I). Double current levels are planned in planar coils and in trim coils.

The sophisticated W7-X systems require advanced numerical modeling. The main global finite element (FE) models have been created and improved for the demanding task (see in Fig. 1). The main structural components of W7-X are presented schematically in Fig. 1 using few cut-outs.

Moreover, the complex support structure of the W7-X magnet system includes a large number of non-linear components (see Fig. 2). Each superconducting coil is connected to the central support structure by two bolted central support elements (CSE) allowing possible opening of the flange under high loadings.

The mechanical inter-coil support structure encompasses many sliding narrow support elements at the inboard part of all five differently shaped NPCs (type 1, 2… 5 coils). The planar support elements (PSE) connect two types of PLC (type A and B) to NPC type 2, 3 and type 4, 5 respectively. One PSE per coil (PSE-A1 to NPC type 2, PSE-B1 to NPC type 5) is a fixed bolted connection, while other PSEs are sliding as the narrow supports. The inter-module lateral supports at outboard part are also bolted connections and only ones inside the module are welded elements. Each magnet system module consists of two flip-symmetric half modules imposing "stellarator symmetry". As a result the central support structure is bolted from ten units. Two of ten magnet system cryolegs fastened to the CSS at the top and sliding/rotating at the bottom bearings installed on machine base are visible in Fig. 1. Toroidal tie-rods fix the position of the magnet system without restrictions for shrinkage during magnet system cooldown. Both the dead-weight and the cryolegs break the stellarator symmetry and introduce slightly different behavior of half modules.

In order to assess the mechanical integrity of the magnet system during design, assembly, commissioning and first phase operation, two global finite element models in ANSYS and ABAQUS were intensely used and benchmarked [4]. The large amount of non-linear components in the magnet system makes its behavior prediction challenging. Other complications are the elements with different order of stiffness and the fact that non-linear geometry option is to be activated to get accurate results. The present strategy is to migrate to one improved ANSYS global model (GM), which is suitable to deliver reliable FE predictions.

In addition, more than 200 detailed local FE analyses of

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critical components have been performed to confirm that all elements are within their structural limits. Such local FE models allow also to study behavior of the critical supports under maximum loadings and beyond.

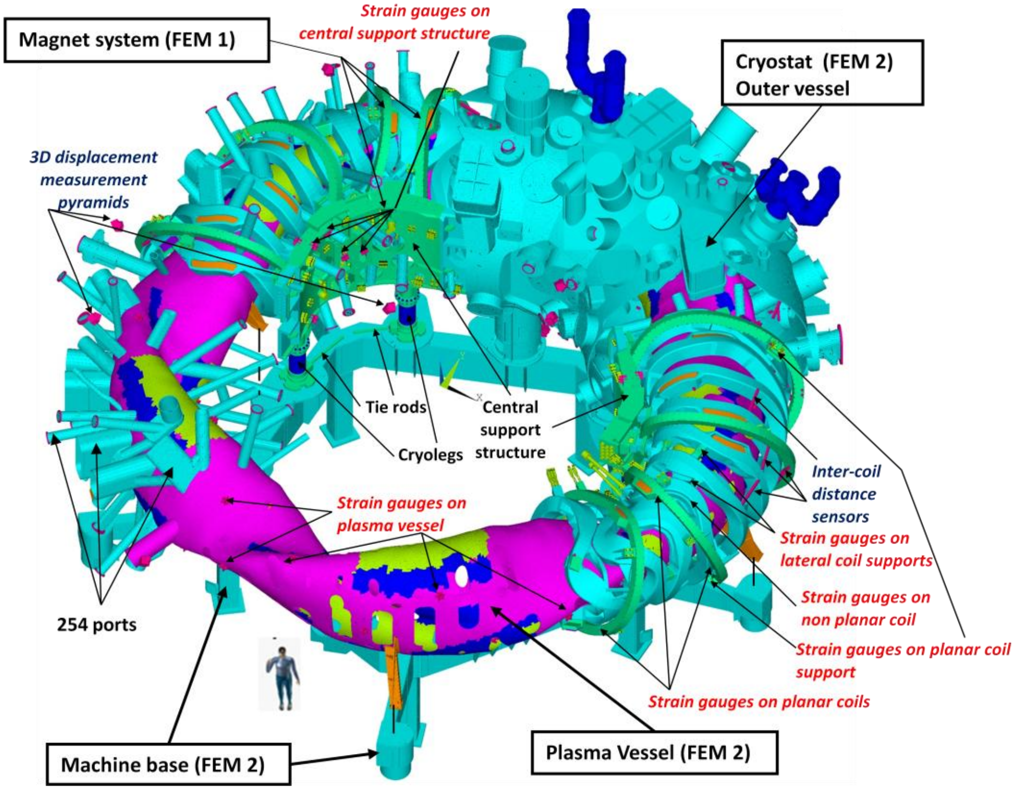

Fig. 1. Fragment of global FE models of cryostat [6] and magnet systems with identification of typical sensor positions.

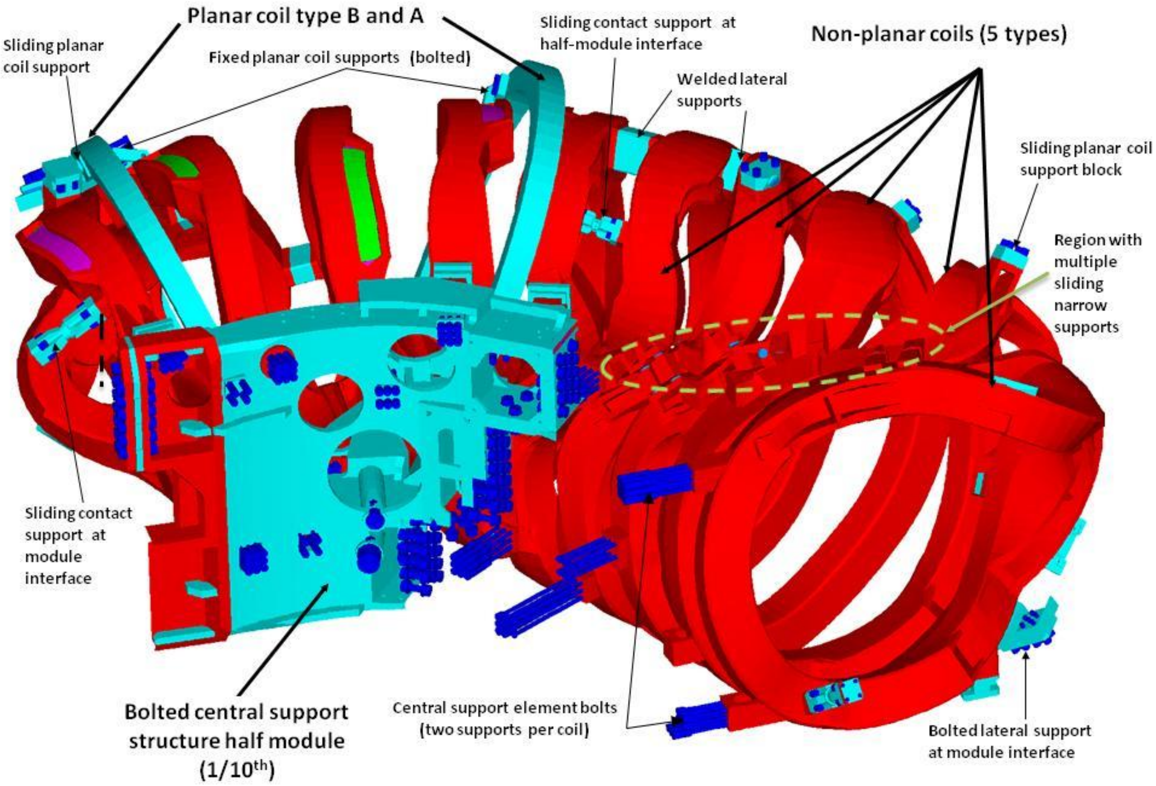

Fig. 2. Fragment of magnet system global FE model with indication of main support types [9].

TABLE I
Coil currents for OP1.1 and OP1.2a operation

	Coil type	Coil current, kA						
		OP1.1 / OP 1.2a		Planned (demanding) new 2.5T regimes during OP1.2a (reference cases only)				
		“J regime” Limiter (0)	“A regime” Standard (2)	High Iota (1)	High mirror (2)	Low mirror (2)	Inward shifted (3)	Low iota (4)*
1	Type 1	12.8	13.5	14.9	14.5	12.6	13.1	12.2
2	Type 2	12.8	13.5	14.9	14.1	13.2	13.0	12.2
3	Type 3	12.8	13.5	14.9	13.4	13.2	13.2	12.2
4	Type 4	12.8	13.5	14.9	12.8	14.2	14.6	12.2
5	Type 5	12.8	13.5	14.9	12.4	14.2	14.7	12.2
6	Type A	0 ÷ 5	0	-10.3	0	0	4.1	9.2
7	Type B	0 ÷ 5	0	-10.3	0	0	-8.2	9.2
Outer Trim coils		1.1		1.8/1.95	1.8/1.95	1.8/1.95	1.8/1.95	1.8/1.95

* Index indicates polarities of planar coils

The unique feature of W7-X is a mechanical instrumentation (MI) system with roughly 800 sensors. The system allows to confirm advanced calculation approaches and results, as well as to guarantee safe operation. In addition to the mechanical data, temperatures, current levels, hydraulic parameters, etc. (altogether more than 3000 signals) are also collected. Their simultaneous monitoring and careful evaluations are the key issue during device commissioning and operation.

The coming project team goals are the physics programs for the operation phase OP1.2a (August 2017 – December 2018) with an inertially cooled divertor, much higher input energy (up to 80 MJ) and longer pulses (up to 60 s).

II. Mechanical Monitoring

A. General Remarks

The direct monitoring of critical components and benchmarking of signals against the results of the non-linear numerical models is the only way to ensure safe operation of the machine. Achievement of the above-mentioned goal is only possible with close interlink between the MI and numerical models.

The mechanical instrumentation is described in detail in [5].

Three main groups of the MI instrumentation were installed in W7-X: strain, distance change, and contact sensors (see Fig. 1).

The primary goal of the global FE models is to predict the stiffnesses and displacements of components, which could affect either plasma equilibrium properties [7] or heat loads on in-vessel components. Therefore, displacement sensors are of great importance. Two ranges of displacements (up to 3 mm and up 20 mm respectively) were originally specified by FE analysis. There are 70 of such latter devices installed in the machine in different locations with different directions (see Fig. 1 and Fig. 3).

Apart from displacement measurements of cold components of the magnet system, also the 3D-movements of all ten magnet system weight supports (cryolegs [8]) need to be monitored. A special 3D displacement measurement unit of pyramid type has been developed and installed at the (warm) bottom of the cryoleg [5].

Possible contacts between the magnet system and the cryostat in the critical narrow gap areas could be detected by an electrical short due to contact between two electrically insulated stainless steel foils. During commissioning and first phase operation no confirmed contacts were detected.

The number and locations of strain gauges (SGs) on the coils were determined before start of coil production when the final loads were not yet known in all details. So some of these sensors are not on optimal positions but still yield valuable information. The locations on the structure elements were determined later with extended knowledge about critical components. First priority was given to instrumentation of Inconel bolts of CSE connections (see fragment in Fig. 5) under bending and tension, critical region with expected yielding on each half-module of the CSS and in the corners of coil blocks for bolted lateral support bridges [9]. Other SGs are located in areas with moderate stress, mainly intended to support the FE model benchmarking.

Part of the MI sensors are distributed symmetrically over the five W7-X modules and the others asymmetrically in order to check the magnet system symmetry and to cover more locations, respectively.

Strong temperature dependence of the SG resistance jeopardizes the measurements at the temperature region below 10K; therefore special compensation procedure is to be implemented [9].

B. Monitoring Approach

Due to MS complex structural design and a limited life time, each step of W7-X commissioning and operation is carefully monitored by a considerable amount of different sensors. Prior to the loading step a set of the boundary or limit values for MI signals are established to distinguish nominal, questionable and critical state of the machine ([10] and [11]) as indicated also in Fig. 3.

Real time monitoring of multiple sensor signals requires careful choice of the way to display the results. In case of MI, it is absolutely necessary to monitor temperatures in parallel with structural signals to avoid misinterpretation. Two or three levels of views, from minimum/maximum/average values down to the individual sensor signal, are found most appropriate. The mechanical monitoring software (MIViewer) [12] includes also signal filtering, and careful signal synchronization. The derived and implemented algorithms are the basis for the current and future deployments in a service oriented W7-X infrastructure. The program is flexible and could be in use for tasks beyond the initial scope. Many functions of MIViewer have been extensively used now for signal post-processing purposes (see Fig. 5 and Fig. 6, Fig. II and Fig. III).

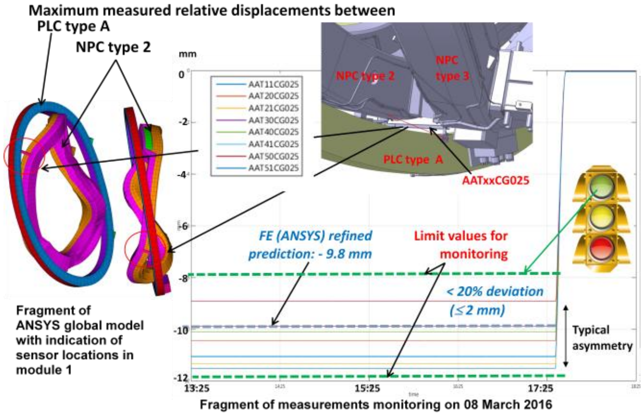

Fig. 3. Results of monitoring for maximum coils mutual displacements between NPC type 2 coils and PLC type A coils. Typical set-up for the wire sensors extracted from CATIA model.

However due to present availability of required electronics only selected set of MI sensor signals is captured and stored in the W7-X experiment archive. Therefore, the approval of the structural integrity by mechanical engineers incorporates also reviews of FE analysis results, especially in case of observed deviations between measurement results and FE predictions.

III. OPERATION MONITORING

A. General Remarks

All measurement systems have been tested prior the operation and it was found that reliable results are at the level of above 20 MPa and 1 mm for strain gauges and mutual displacements between coils respectively. Measurement pyramids have been more accurate (0.1 mm – 0.5 mm for different directions) and fully reliable.

Structural integrity of the magnet system with respect to electromagnetic forces is of main interest. Therefore, the signals had been set to zero when the operation temperature of ~4K is reached. Moreover, such zeroing had been done basically each time after temperature increase above 10K. Later it was found that with such approach the residual stress could be neglected as well as the residual displacements, which are below 0.5 mm with exceptions for cryoleg sliding. However, originally implemented zeroing process did not care about winter/summer time shift; therefore it was decided to create a special signal zeroing stream to avoid the problem, to accelerate signal post-processing and to guarantee repetitive procedure.

IV. PREPARATION FOR NEXT PHASE OPERATION

A. General

The coming operation phase with an inertial cooled divertor allows much higher input energy and longer pulse. Many engineering challenges have been resolved to provide the abilities to achieve the goal [14].

Multiple operation cycles with higher energy could significantly increase the temperature of plasma vessel, parts of passively cooled ports and in-cryostat bellows. It is expected that much higher heat flux is to be delivered on the cryogenically cooled structures with corresponding increasing of temperature by few degree. This results in considerable SG signal changes. In order to avoid false alarm and to guarantee smooth operation, it is necessary to implement a compensation of the effect using signals of temperature sensors located on the cryogenic structures.

Moreover it is expected that magnetic 2.5 T configurations are to be extended not only to several reference magnetic configurations fully analyzed before [4] (see Fig. I), but also to many other regimes proposed by physicists with the goal to scan different plasma parameters. Both of these facts are considered in the present preparation activities.

B. Filtering of New Regimes

At present, the input for the numerical analyses is a set of coil group currents and indication of the induction on axis. Probably in the future it is possible to get from physicists a set of already prepared electro-magnetic load distributions along winding pack axis for engineering considerations.

General strategy for the approval or rejection of a proposal is presented in Fig. 4. First branch is an easy acceptance using 10%-rule, which is safe and allows to use already prepared data for MI monitoring. The previous analyses experience indicates that current levels in neighboring coils and their difference define loads on the support elements and main components. Therefore the following formulation is in use:

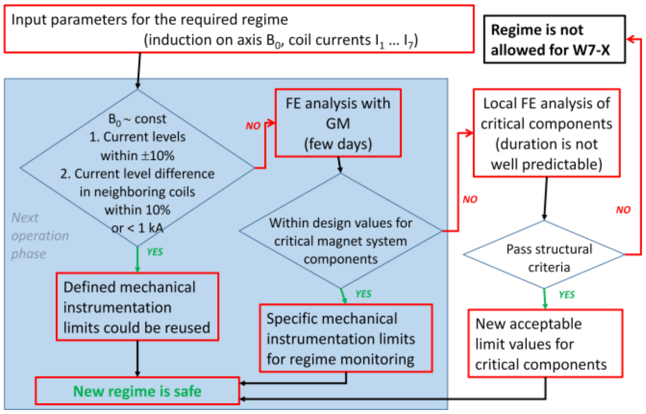

Fig. 4. Filtering of configuration proposals from physicists.

$$\mathrm{I}_\mathrm{i}^{\mathrm{new}} \text{ within } \mathrm{I}_\mathrm{i}^{\mathrm{ref}_\mathrm{k}} \mp 10\%; \tag{1}$$

$$\mathrm{I}_\mathrm{j}^{\mathrm{new}} \text{ within } \mathrm{I}_\mathrm{j}^{\mathrm{ref}_\mathrm{k}} \mp 10\%; \tag{2}$$

$$\left(\mathrm{I}_\mathrm{i} - \mathrm{I}_\mathrm{j}\right)^{\mathrm{new}} \text{ within } \left(\mathrm{I}_\mathrm{i} - \mathrm{I}_\mathrm{i}\right)^{\mathrm{ref}_\mathrm{k}} \mp (10\% \text{ or } 1\mathrm{kA}) \tag{3}$$

where I_i^{new}, I_j^{new} - currents in neighboring coils defined in a proposal; $I_i^{ref_k}$, $I_j^{ref_k}$ – corresponding current levels in one of reference regime (k).

Only if all conditions (1)-(3) are satisfied, the new configuration is accepted. If that is not the case, FE analysis with global model could deliver the answer: are the generalized forces and moments in all supports and components within design values. If so, new regime is safe, but new limits for MI monitoring are to be prepared as indicated in second branch of the diagram. However, if global model results are not within design values, local analyses of critical components are to be launched. Time period for such complex and sometimes non-linear elasto-plastic local analysis is difficult to predict, therefore it is agreed during next phase of operation to permit only regimes satisfying two first branches of evaluations.

Present application of 10%-rule has shown that approximately 30% of physics proposals could be accepted without additional FE calculations.

C. Detail Post-processing of Cyclic Behavior

The post-processing functions of MIViewer have been intensively used to check stable cyclic behavior of the machine. Typical examples of the summary tables for monitored strain gauges of NPC type 2 are presented in Fig. II and Fig. III for selected time periods with similar loadings. It is clear visible that for similar cycles during the same monitoring day (Fig. II), signal results (in blue, italic in all tables) are almost equal, for cycles with few months span (Fig. III), they are within few megapascals. The deviations (in % and in absolute values) from FE predictions (in black, bold in all tables) are also clear visible there. In order to sort them out and to highlight, status columns are in use: Reliable (deviations are below 20% and values above thresholds), Questionable (deviations are below 30% or values below thresholds) and NotReliable (for other cases).

It is also well visible that a failure occurred in the sensor installed on coil number 59 (AAB59CY001, marked in red). Initially good results from 6th of July 2015 (Fig. III) jump to extreme value one week later (14th July, Fig. II). Due to the fact that other sensors in the vicinity showed no deviations, the sensor was ranged as malfunctioning one together with other ~ 5% MI sensors.

TABLE II

Non planar coil type 2 case von-Mises equivalent stress levels, MPa. Comparison of FE prediction (GM 6.01) with measurements for cycles of Case A

Sensor name	FE results	14-Jul-2015 09:07-09:39			14-Jul-2015 10:36-13:40			Status*		
	pure	*pure*	Diff	%	*pure*	Diff	%	R	Q	NotR
AAB32 CY001	**110**	*120*	10	9	*120*	10	9	X	.	.
AAB32 CY002	**127**	*152*	24	19	*152*	25	19	X	.	.
AAB39 CY001	**109**	*84*	-25	-23	*84*	-25	-23	.	X	.
AAB49 CY001	**110**	*176*	66	60	*177*	67	61	.	.	X
AAB12 CY001	**109**	*102*	-7	-6	*103*	-7	-6	X	.	.
AAB12 CY002	**129**	*226*	97	75	*226*	97	75	.	.	X
AAB59 CY001	**110**	*738*	628	571	*738.*	628	571	.	.	X

* Reliable, Questionable, NotReliable

It is planned to use such kind of fast overview reports for repetitive cycles of case J and case A at the beginning of new operation phase in order to confirm stable MS behavior after more than one year period including W7-X upgrade activities.

Questionable and non-reliable sensor locations indicated in post-processing tables for all components were checked in the finite element model to confirm their adequate representation as reported in Chapter IV.E.

Another application of monitoring functions is an overview study for the whole campaign. Highly pre-stressed Inconel bolts instrumented as shown in Fig. 5 and described in [5] have been carefully checked. Some pre-stress losses have been found during operation cycles after fast discharges of the magnet system and after long standby mode. The average rate is approximately 0.1 MPa per 10 operation cycles for most critical bolts indicated by sensor AAD10HG611CY9 and AAD20HG611CY7.

TABLE III

Non planar coil type 2 case von-Mises equivalent stress levels, MPa. Comparison of FE prediction (GM 6.01) with measurements for cycles of Case J

	FE results	06-Jul-2015 11:13-11:50			07-Sep-2015 09:55-16:29			13-Jan-2016 12:45-18:22			10-Mar-2016 12:10-17:40			Status*		
Sensor name	pure	pure	Diff	%	pure	Diff	%	pure	Diff	%	pure	Diff	%	R	Q	NotR
AAB32CY001	**98**	*108.*	10	11	*108*	10	11	*104*	6	6	*103*	5	5	X	.	.
AAB32CY002	**133**	*161*	28	21	*157*	24	18	*153*	20	15	*153*	20	15	.	X	.
AAB39CY001	**98**	*75*	-23	-24	*75*	-23	-23	*72*	-27	-27	*71*	-27	-28	.	X	.
AAB49CY001	**98**	*158*	59	61	*157*	59	60	*151*	53	54	*150*	52	53	.	.	X
AAB12CY001	**98**	*92*	-6	-6	*91*	-7	-7	*88*	-10	-10	*86*	-12	-12	X	.	.
AAB12CY002	**135**	*242*	107	80	*233*	98	73	*229*	94	69	*228*	93	69	.	.	X
AAB59CY001	**98**	*118*	20	21	*727*	629	642	*722*	625	637	*723*	625	638	.	.	X

* Reliable, Questionable, NotReliable

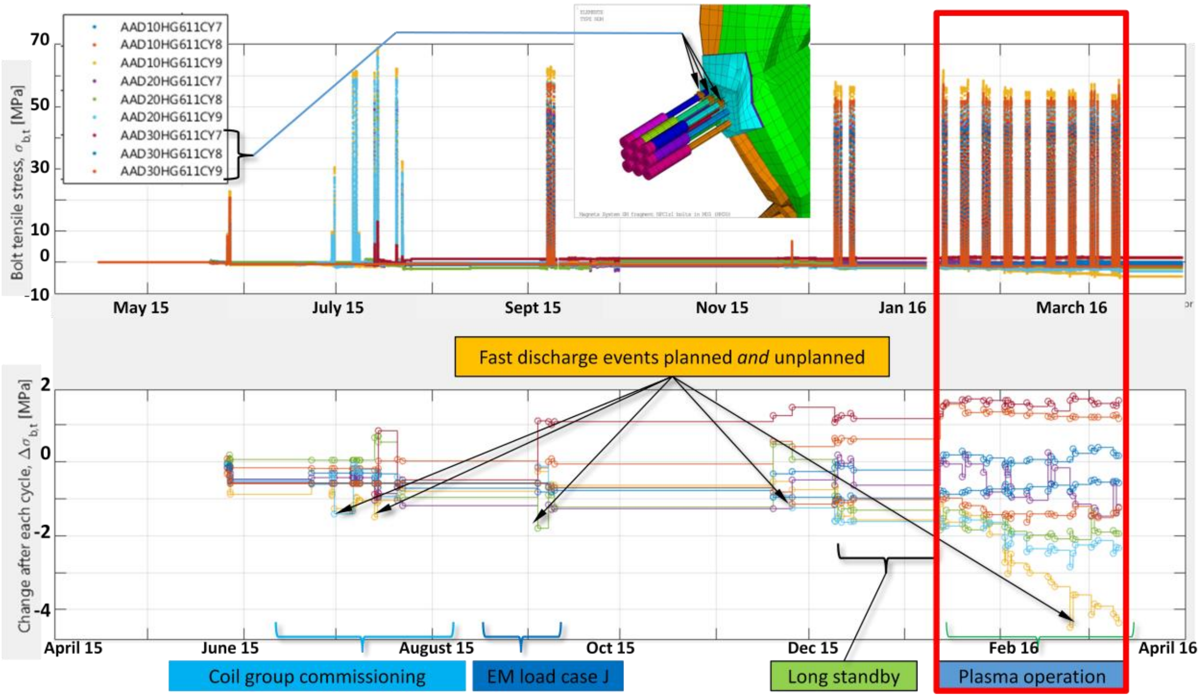

Fig. 5. Detection of all cycles measured in critical bolts (upper graph) and calculation of remaining bolt pretention offsets (bottom graph). Fragment of FE model presents coil, coil extension, bolts and sleeves as well as strain gauge locations.

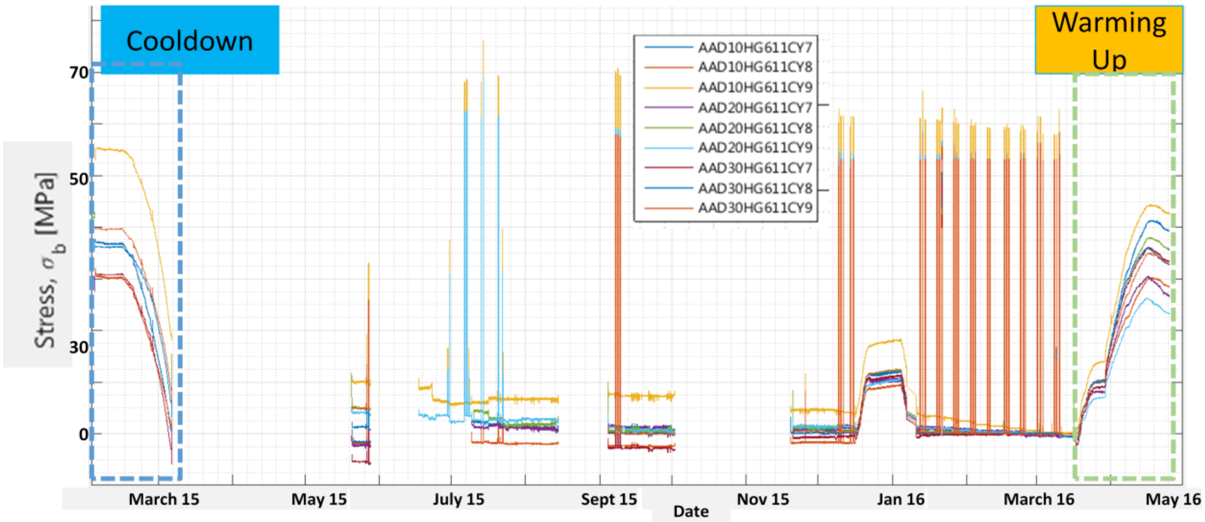

Fig. 6. Estimation of bolt pretention offsets (MPa) due to cooldown/warming up cycle (see detail values in Fig. IV).

TABLE IV

BOLT PRETENSION OFFSET DUE TO COOLDOWN/WARMING UP CYCLE, MPA

Bolt sensor name	Bolt pretention offset, MPa
AAD10HG611CY7	1.66
AAD10HG611CY8	-3.65
AAD10HG611CY9	-9.97
AAD20HG611CY7	-3.89
AAD20HG611CY8	-6.04
AAD20HG611CY9	-14.19
AAD30HG611CY7	1.99
AAD30HG611CY8	-3.41
AAD30HG611CY9	-6.96

As a result, the expected bolt pre-stress losses during next operation phase are to be within 13 MPa. Additional attention is paid to the bolt pre-stress degradations due cooldown/warming up cycle. The values are limited to 14.2 MPa as listed in Fig. IV for first cooldown cycle. Losses caused by next cooldown/warming up cycle are difficult to predict due to insufficient statistics. The close supervision of the bolts is to be extended during next commissioning/operation steps.

Bolt pre-stress degradation behavior is also observed in the summary tables for cycles (similar to Fig. III).

D. Monitoring Improvements

The monitoring improvements are being implemented into two main directions: 1) to include better interpretation of the signals from the sensors (e.g. temperature compensation as described below), 2) to accelerate a process of signal extractions, their comparison with three levels of criticality and/or to indicate location of the critical sensors. Full list of improvements includes the followings:

- Change of strategy for data extraction and storage: daemon process runs and collect required raw data, while post-processing of meaningful values are delivered only on request;
- Zeroing stream is organized and written in automatic manner. Zeroing values are updated after each coil energizing start. The software allows also a possibility to have required offset, which is important for long period overviews (e.g. for cryolegs and bolts during cooldown);
- Easy review on selected sensor locations is to be completed;
- Additional sensors to monitor in parallel (mainly temperature: in-vessel components, thermal insulations, etc);
- Ramping up with simultaneous monitoring and structural assessment is developed and to be tested;
- Temperature compensation with Kalman filter prediction (see [9] for details) is to be fully tested.

E. FE Global Model Improvements

The "workhorse" of the engineering team is a magnet system global 72-degree FE model (v.6) prepared in ANSYS. The main improvements are presented in [9] for v. 6.01, while recent activities have been devoted to the introduction of model modifications in order to deliver more accurate signal predictions (v. 6.02). The driving factor was the plan to double the current levels in planar coils during the next operation phase (see Fig. I). The resulting forces/moments in the relevant components should be higher by factor of 2 ~ 3. Therefore a campaign to clarify several discrepancies between FE model predictions and measurements as well as a few parametric studies to see their influences on the monitoring signals has been launched with the main focus on PLCs and PSEs.

TABLE V

IMPROVEMENT OF SIGNAL PREDICTION AFTER REFINEMENT OF FE MESH (SEE FIG. 7)

Sensor name	Case J (2.5T), MPa		
	Original GM 6.01	Measurements	Refined GM 6.02
AAC52CY002	**18.0**	*22 - 24;*	**20.0**
AAD30HH930R	**12.0**	*24.2*	**30.0**
	Case A (2.5T), MPa		
AAD10HH930	**20.0**	*62.0*	**40.0**
AAD11HH930	**24.0**	*46.6*	**35.0**
AAD31HH930	**24.0**	*51.8*	**35.0**

Two main reasons for discrepancies have been identified: 1) distances between strain gauge positions and nodes in use for FE result extractions; 2) inaccurate assumption about measuring wire inclination. Typical example of the required mesh refinement for fixed support of planar coil type B (PSE B1) is presented in Fig. 7 and corresponding deviation reductions (from GM 6.01 to GM 6.02) are listed in Fig. V.

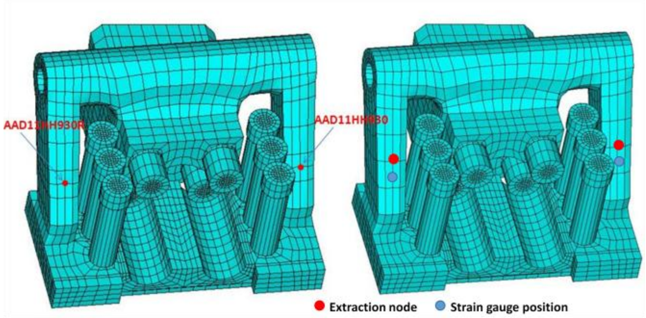

Fig. 7. Refinement of bolted planar coil support B1 for better FE prediction of strain gauge signal (right: original mesh, left: refined mesh).

The correction of wire inclination as indicated in Fig. 8 has different effects on different mutual coil displacement predictions (see Fig. VI), but main discrepancy (highlighted in yellow) is gone and the deviations after modifications are in general within 1.1 mm and bellow 20%.

TABLE VI

IMPROVEMENT OF SIGNAL PREDICTION AFTER REFINEMENT OF WIRE INCLINATION IN FE MODEL (SEE FIG. 8)

Sensor name	FE results GM 6.01	Measurement (same cycles as in Fig III)				FE results GM 6.02
		1	*2*	*3*	*4*	
AAT10CG021	**-1,67**	*-2,48*	*-1,62*	*-2,16*	*-2,64*	**-1,59**
AAT10CG022	**8,14**	*8,42*	*7,94*	*8,14*	*8,06*	**8,10**
AAT10CG023	**-1,60**	*-1,63*	*-1,76*	*-1,62*	*-1,39*	**-1,88**
AAT10CG024	**-3,41**	*-2,42*	*-2,57*	*-2,61*	*-2,52*	**-2,57**
AAT20CG025	**-10,81**	*-11,12*	*-10,33*	*-10,55*	*-10,59*	**-9,77**
AAT10CG025r	**-6.00**	*-3,96*	*-3,73*	*-3,86*	*-3,88*	**-4,04**
AAT10CG026	**-0,57**	*-1,27*	*-1,61*	*-1,24*	*-1,26*	**-0,52**

Next version of the ANSYS global model (v. 6.03) with deviations between all specified sensor positions and FE result extraction nodes below 20 mm is presently in preparation for the next phase operation.

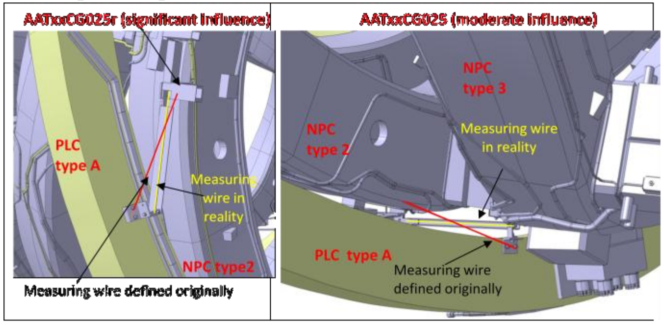

Fig. 8. Typical discrepancies between originally assumed measurement wire inclinations and installed ones.

V. STATUS

The successful trim coils (TC) commissioning with a full current allows to use the coils as a very powerful tool for the magnet field adjustment during coming OP1.2a operation. The TC commissioning has been accompanied by displacement measurements and assessment of rubber pad behavior in the coil supports.

The collection and analysis of the MI signals are limited by number of expensive signal transformers needed to connect the sensors to the W7-X programmable logic controller system. The selection of sensors to be connected is done in favor of highly loaded bolts and planar coils, but selection task is to be repeated prior to each step of the commissioning and operation. Few additional electronics have been purchased to reduce number of electronics re-plug-ins.

It is expected that additional useful information will be collected during OP1.2a phase to minimize deviations for relevant sensors further with probabilistic parameter adjustment in FE models.

The agreement for the next operation phase could be summarized as the followings:

- Slow current ramping up to test monitoring procedure with the simultaneous MI assessment.
- Only electromagnetic regimes satisfying criteria without FE local analysis are accepted.
- Temperature compensation for strain gauges is to be introduced and checked.
- Level of current and number of fast discharges for test purposes are to be reduced.
- Regular assessment of the bolt preload degradation is to be performed.

VI. CONCLUSIONS

The following conclusions can be drawn from recent activities prior to next W7-X operation phase:

- Results of comparison between numerical modeling and mechanical instrumentation measurements show good agreement after introduced modifications in the numerical models;
- Areas of most attention are defined;
- Temperature compensation procedure is developed and is to be tested in order to be fully functioning during most demanding operation phases;
- Approach for fast approval of an extension of physics program is developed.

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