

Hybrid Integral-Differential Simulator of EM Force Interactions / Scenario-Assessment Tool with Pre-Computed Influence Matrix in Applications to ITER

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1. Progress on the way of preparations to ITER procurement

- The efficient method of modeling EM mechanical interaction forces between components of a large tokamak has been proposed and considered for ITER.
- The hybrid model for calculating EM forces on coils and magnets has been developed, according to the proposed method and approach.
- Sensitivity/influence matrices have been produced for the elements of ITER magnetic system, including all coils and magnets.
- The obtained matrices and profiles have been used for the multi-scenario assessment and systematic specification of EM loads on ITER coils and magnets in all considered operating regimes and plasma transients, including full load ranges, maximum loads, envelopes and the most critical cases.
- The reference design values and the ITER Design Description Document (DDD) data have been benchmarked against the new model and systematic results.

2. Status

- The benchmark of reference design values from ITER DDD (obtained by traditional analyses over the past years) showed their essential consistency with new results.
- The basic principle of considering bilateral configurations, supported by the technology of functional approximation of distributed data by the continuous analytical interpolants, is applicable to asymmetric loading or faulty systems and continuously distributed currents (shells, solids).
- The developed global model of interactions, together with the "meshless" analytical format of output provide the source of self-consistent and transferable data on mechanical loads as input for structural analyses of components, assemblies and supporting structures at any arbitrary scenarios, regimes of operation and transients.
- The obtained results and matrices (transforming the vector of currents to the full set of Lorenz forces) form a basis for a relatively simple and robust linear force processor as a specialized module of a global simulator for diagnostic, operational instrumentation, monitoring and control, as well as a scenario assessment tool.
- The simplicity and computational efficiency of the operative part of the developed hybrid model permits real-time calculations of forces (total and distributed).

3. Some critical issues, next steps and main challenges towards the commissioning and pre-nuclear operation of ITER

- The performed study clearly demonstrated a necessity to restrict the operational space to certain limits, determined by the loading capacity of structures.
- Integration of the force-calculating units / processors / predictors / simulators with Plasma Control System (PCS), other control and safety systems, pulse control allowables, interlock and safety limits must assure a solid margin to the structural limits in order to prevent any risk of magnets and structures overloading. This will insure the investment protection, as well as personnel and environmental safety during the machine operation. The integrated numerical simulators, including mechanical force processors, quantifying the predicted state of structures in a space of operational parameters, should be an implicit part of the system.
- The availability of simulators is one of necessary pre-requisites for entering the pre-nuclear Tokamak Operation phase. In applications for either phase, the key aspect of simulators (models) is their computational efficiency and robustness. The latter can be ensured by the maximum reasonable simplification/optimization of the model and its adequacy to the considered problem/system and to the practical needs.
- The use of hybrid models with pre-computed part, similar to the presented model, permits running the operative part in real-time mode, and such functionality can be integrated with the operational diagnostic and control systems of the real machine.