MHD aspects of NSTX-U & Theory cooperation

Leonid E. Zakharov

Princeton Plasma Physics Laboratory, MS-27 P.O. Box 451, Princeton NJ 08543-0451

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Linear stability and perturbed equilibria in NSTX-U

Leonid E. Zakharov, Luca Guazzotto

Objectives	***Comprehensive consideration of linear and quasi-linear MHD stability. It includes:*** ***(a) creation of a quasi-linear tokamak equilibrium code (PEQC) for 3-D perturbations;*** ***(b) extension of stability analysis to the plasma edge, including separatrix;*** ***(b) use PEQC for simulation of external perturbations at the plasma edge in NSTX-U;*** ***(c) extension of PEQC to self-consistent simulations of the Scrape off Layer currents.*** ***(d) addressing the needs in stability analysis of the LiWF regime on NSTX-U with finite current density and pressure gradient at the separatrix.*** ***(e) performing 3-D (quasi-linear) simulations of the wall touching kink mode (WTKM)***
Motivation	***(a) ideal MHD is insufficient for understanding edge stability of NSTX-U plasma;*** ***(b) the existing IPEC is not an equilibrium code (extension of the ideal MHD DCON);*** ***(c) the use of vacuum field perturbations neglects the plasma response;*** ***(d) attempt to reveal the physics mechanism of the thermal quench.***
Scope of work ***1 ZFTE****	***(a) implementation of ψ-form of the energy principle (advantages: driving effects are explicit, applicable for both ideal and non-ideal plasma, simple interface with equilibrium, no convergence problem);*** ***(b) work is in progress on a reduced MHD version of PEQC under IO contract on RE;*** ***(c) development of full version of PEQC.***
Validation:	***New, ψ- form of energy principle resulted in 2005 in predictions of stabilization of ELM in Li assisted regimes***
Application:	***(a) global stability, beta limits and edge stability in NSTX-U in the presence of RMP and active plasma control;*** ***(b) simulations of RE production and losses by interfacing PEQC with IO set of codes on plasma jet and energetic particle modeling.***
Deliverables:	***(a) Guidance and assistance in developing the lithium wall fusion regimes;*** ***(b) provide practical tools for simulation of thermal quench, WTKM and RE losses;*** ***(c) create a science based bridge for application of NSTX stability results to ITER.***

* ***ZFTE*** stands for one year Zakharov's full time equivalent.

Hiro currents and simulation of vertical instability

Leonid E. Zakharov

Objectives	***Create understanding of VDE and interpretation of plasma-to-wall currents in NSTX-U*** ***(a) develop a realistic numerical model of vertical instability;*** ***(b) create a practical model for 3-D conducting in-vessel elements of NSTX-U;*** ***(c) provide a guidance for designing special tiles for measuring the Hiro currents;*** ***(d) clarify the role of Hiro, Evans, eddy, and "halo" currents in VDE.***
Motivation	***(a) Theory has undermined the community shared paradigm of "halo" currents;*** ***(b) "halos" have been dismissed as asymmetric wall currents in all JET VDEs;*** ***(c) VDE is the cleanest case for developing a basic understanding of disruptions;***
Scope of work 1 ZFTE*	***(a) modify ESC code for simulation of a n=0 linear vertical mode in NSTX-U;*** ***(b) provide a guidance for installation in NSTX-U Hiro currents sensors (as in EAST);*** ***(c) create a 3-D model of the conducting in-vessel components of NSTX-U using*** `Cbshl` ***code;*** ***(d) modify ESC for simulations of VDE, including plasma-wall current sharing.***
Validation:	***(a) calibrate the 3-D wall model against calibration shots in LTX and NSTX-U;*** ***(b) reproduce both magnetic signals and tile/Hiro currents in VDE in NSTX-U;***
Application:	***(a) amplitudes and localization of forces for design purposes;*** ***(b) appropriate interpretation of measurements for the plasma stability control;*** ***(c) assessment of VDE effects on the liquid lithium layers in NSTX-U;***
Deliverables:	***(a) realistic physics & numerical model of VDE in tokamaks;*** ***(b) new diagnostics for the Hiro currents in the wall;*** ***(c) simulation tools for assessing the effect of VDE on ITER beryllium tiles.***

* ***ZFTE*** stands for one year Zakharov's full time equivalent.

3-D magnetic fields and equilibria

Leonid E. Zakharov, Egemen Kolemen, Samuel Lazerson

Objectives	***Develop fast numerical tools for 3-D analysis in NSTX-U and 3-D equilibria in general*** ***(a) implement Hamada principle (unused since 1960) for the case of good flux surfaces.*** ***(b) implement the Reference Magnetic Coordinates (RMC) for ergodic fields;*** ***(c) create a fast 3-D equilibrium code LEE based linearized equilibrium equations.***
Motivation	***(a) needs of plasma edge physics (RMP, SoL) and disruptions simulations;*** ***(a) widely used VMEQ does not treat properly 3-D resonance surfaces;*** ***(b) PIES with tracing field lines is slow and impractical;*** ***(c) two innovative elements in 3-D theory: LEE and RMC promise high performance.***
Scope of work 2 ZFTE*	***(a) develop a 2-D version of LEE for fast calculations of tokamak equilibria;*** ***(b) extend the 2-D version on tokamak configurations with perturbed magnetic field;*** ***(c) develop a 3-D version for configurations with good flux surfaces;*** ***(d) implement the RMC into LEE for configurations with ergodic magnetic fields.***
Validation:	***(a) benchmark against 2-D ESC;*** ***(b) use of LSODE with a prescribed accuracy in solution.***
Application:	***(a) RMP-ELM analysis of NSTX-U plasma;*** ***(b) 3-D effects from the in-vessel conducting components in NSTX-U;*** ***(c) assessment of VDE effects on the liquid lithium layers in NSTX-U;***
Deliverables:	***(a) science based loop hole free 3-D equilibrium solver;*** ***(b) a basic component of the disruption simulation code.***

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Disruption simulation code (DSC)

Leonid E. Zakharov, Sergei Galkin (FAR-TECH, Inc)

Objectives	***Create a DSC and MHD simulations basis consistent with the basic properties of the tokamak plasma: high anisotropy, and unrestricted motion to the wall.*** ***(a) implements RMC based grids, consistent with the high plasma anisotropy;*** ***(b) create the free boundary plasma with no wide spread "salt water" limitations;*** ***(c) interface the core MHD with the boundary physics and realistic wall geometry;*** ***(d) following Kadomtsev-Pogutse get rid of magneto-sonic limitation on the time step***
Motivation	***Implementation of an appropriate plasma physics into MHD simulations is urgent:*** ***(a) 3-D MHD codes use hydrodynamics, rather than plasma physics, schemes;*** ***(b) NIMROD and M3D are irrelevant to tokamak disruption physics because of Vn=0;*** ***(c) Both failed of addressing critical ITER needs in assessing disruption forces ;*** ***(d) Wall touching kink mode (WTKM) needs to be simulated;***
Scope of work ***2 ZFTE****	***(a) implementation of two versions of adaptive grids: (1) clouds of points, (2) RMC;*** ***(b) interfacing core plasma calculations with 3-D model of the in-vessel structures of tokamaks;*** ***(c) validation of model against the LTX (in future NSTX-U) calibration shot data;*** ***(d) initiation of regular simulations of VDEs mixed with kinks in NSTX-U.***
Validation:	***(a) reproducing in simulation the JET VDEs measurements;***
Application:	***(a) ITER urgent needs in resolving disruption problem;*** ***(b) identification of similarity in disruptions physics between NSTX-U and tokamaks;*** ***(c) assessment of the effect of disruption on in-vessel components in NSTX-U***
Deliverables:	***(a) a plasma physics based MHD numerical code for disruption simulations.;*** ***(b) 2-D version of DSC was created in 2011 and is capable of simulation of WTKM.***

Real Time Forecast (RTF) of tokamak discharges

Leonid E. Zakharov

Objectives	*Creation of a real time mechanism for prediction of discharge parameters:* *(a) enhance the existing equilibrium reconstruction technique with variance analysis;* *(b) create a fast and flexible for real time modifications a transport simulation code;* *(c) implement the transport code profiles as "signals" in reconstruction;* *(d) arrange ahead-of-time (e.g., in the next $0.5\tau_E$) predictions of the discharge.*
Motivation	*ITER: no more empirical approach for specifying disruption-free operations space.* *(a) rigorous theory was created for assessing validity of equilibrium reconstruction.* *(b) ESC was complemented with new abilities;* *(c) ASTRA transport code is interfaced with ESC; in 2007 demonstrated RTF abilities;*
Scope of work *0.5 ZFTE**	*(a) implementation of variances technique into equilibrium reconstruction;* *(b) development an interface of equilibria with a separatrix and transport codes;* *(c) utilization of the transport calculated profiles as signals in reconstruction;* *(d) arrange both real time adjustment and predictive mode for transport simulations.* *(e) real time interface with NSTX-U diagnostics;*
Validation:	*(a) post discharge reproduction of the experimental data on NSTX-U;* *(b) field test of REFIT reconstruction on NSTX-U enhanced by RTF abilities;*
Application:	*(a) plasma control for NSTX-U, DIII-D and for JET, EAST, KSTAR, ITER;* *(b) validation of the transport and stability models for tokamak plasma;*
Deliverables:	*(a) ASTRA-ESC code system s a prototype of RTF;* *(b) enhanced plasma control system for NSTX-U;*

Flux tube equilibria at the plasma edge

Leonid E. Zakharov

Objectives	***Create an understanding the flux tube phenomena at the plasma edge in NSTX-U.*** ***(a) create the basic theory mechanism for consideration of flux tube configurations;*** ***(b) implement the theory into 3-D flux tube numerical code;*** ***(c) interface the code with NSTX-U measurements for developing interpretation;***
Motivation	***Simplistic understanding of the plasma edge as a set of flux surfaces was shaken by RMP experiments on DIII-D and SoL measurements.*** ***(a) there is no basic justification of the "ideal" MHD plasma model for edge stability;*** ***(b) DIII-D proved that field lines from the pedestal region are linked with the tiles;*** ***(c) the role of SoL currents is not yet revealed;*** ***(d) edge 3-D MHD remains essentially an untouched area.***
Scope of work ***1 ZFTE****	***(a) extend the space curve equilibria theory to flux tube at the tokamak edge;*** ***(b) create a numerical code for extraction of edge flux tube parameters from NSTX-U configurations;*** ***development an interface of equilibria with a separatrix and transport codes;*** ***(c) create a 3-D code (in the reduced MHD approximation) for flux tube equilibria;*** ***(d) arrange processing the NSTX-U data on flux tube events;***
Validation:	***(a) reproduction of the experimental measurements on NSTX-U;***
Application:	***(a) plasma edge stability control;*** ***(b) assessment of the edge stability in the LiWF regime.***
Deliverables:	***(a) the theory of the flux tube equilibria for the plasma edge and astrophysics phenomena;*** ***q*** ***(b) the flux tube equilibrium code interfaced with NSTX-U data base.***