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O-1.001, *Monday June 27, 2005*

The Role of the m/n=3/2 Tearing Mode in the Hybrid Scenario and Extension of the Hybrid Operating Regime*

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The hybrid scenario has been proposed as a robust operating scenario for high performance operation of ITER. It is intermediate between the standard, high current scenario and the steady-state Advanced Tokamak scenario, and it provides high gain (Q) for long pulses. Understanding the physical mechanisms underlying the improvement in the beta limits in the hybrid regime will allow more confident implementation of this scenario in ITER. In hybrid scenario tokamak plasmas, the central current density is lower and the central safety factor is higher than is expected for comparable conventional scenario plasmas. A key feature of the hybrid scenario in DIII-D is the presence of an m=3, n=2 neoclassical tearing mode. This essentially stationary island structure is associated with the reduction (at $q_{95} \leq 4$) or elimination (at $q_{95} \geq 4$) of sawteeth. The decreasing sawtooth amplitude reduces or eliminates a trigger for the deleterious m=2, n=1 neoclassical tearing mode. The 2/1 mode limits the achievable beta in the conventional H-mode scenario. The effect of the 3/2 mode on the sawtooth amplitude has been demonstrated using localized ECCD (≤50 kA) to enhance or suppress the mode amplitude. With co-ECCD the mode is suppressed and sawteeth appear. With counter-ECCD the 3/2 amplitude increases and small pre-existing sawteeth are suppressed. The sawteeth do not recur after the end of the counter-ECCD pulse. A variety of physical mechanisms may be involved in the regulation of q(0) and the sawteeth by the 3/2 mode. There is significant time-asymmetric modulation of the mode amplitude by ELMs, as well as a small noisy amplitude modulation which also shows evidence of time-asymmetry. Initial modeling indicates that such time-asymmetries can move poloidal flux from the region between the magnetic axis and the 3/2 mode to the exterior region. There may also be a true dynamo present, with conversion of mechanical to magnetic energy. Because the stationary state always has q(0) close to one, even in the absence of sawteeth, it is likely that the observed 2/2 component of the 3/2 mode is playing a role.

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Study of MHD events initiated by pellet injection into T-10 plasmas

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There are several events which might be responsible for ultra fast transport [1] of heat and particles during pellet ablation stage in a tokamak. Those are jumps of transport coefficients, plasma drifts in the pellet vicinity and MHD events with time scale significantly shorter than the pellet ablation time. The role of the latter is still not very well understood due to a lack of studies. This paper is devoted to detailed study of the effects during the pellet ablation phase (~one millisecond) with main objective to determine the relation between pellet (material Li, C, KCl, size and velocity) and plasma parameters (q-value a the pellet position, plasma density and temperature) which initiate microsecond MHD events in plasma.

The pellets were injected into both into Ohmic and ECE heated plasmas (up to 3 MW) in the T-10 tokamak at various stages of the plasma discharge, in a wide range from the very beginning up to the post-disruption stage.

It is observed that at some conditions a pellet ablates in the plasma without accompanying MHD events. This occurs at the highest plasma densities even if a pellet penetrates through q=1 magnetic surface. The ablation rate corresponds to NGSM in this case.

Small scale events may occur near rational magnetic surfaces and the ablation rate fluctuations may be explained by reconnection. Both increase of the longitudinal heat flow due to plasma convection from higher temperature region and growth of the electric field generating supra-thermal electrons may be responsible for the enhanced ablation. Large scale MHD events envelop a region inside $q<3$. It is observed that the MHD-cooled area is not poloidally symmetric.

Mechanisms of the phenomena observed and their consequences on tokamak operation are discussed.

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Self-organized temperature redistribution of m=1 mode (sawtooth) oscillation on TEXTOR*

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A novel 2-D Electron Cyclotron Emission Imaging (ECEI) system [1] for measuring electron temperature fluctuations has been applied to study the physics of the sawtooth oscillation in TEXTOR. 2-D images with high spatial resolution [128 pixels covering 8 cm (radial) x 16 cm (vertical)], and high temporal resolution (up to ~5 microsec) have revealed the details of 2-D images of the electron temperature fluctuations during the precursor phase and the crash time of m=1 (sawtooth) oscillations, with a level of detail that is not accessible through conventional methods (1-D ECE and/or tomography). A new paradigm for the m=1 oscillation has been developed based on the evolution of the 2-D electron temperature image with the accumulated knowledge from previous experimental results [2] on TEXTOR. The evolution of the 2-D image clearly illustrates that the crash can occur in almost every direction along the q~1 surface (high and low field sides) and the heat transported out of the q~1 surface follows the magnetic pitch and symmetrically accumulates outside of the inversion radius before initiation of the diffusive process. These observations suggest that the sawtooth crash is likely toroidally global, but poloidally localized. The new reconnection model is based on the local magnetic field from the current carrying m/n=1/1 layer which has a crescent shape hugging the m=1 mode outside the inversion radius. The physical dimensions of this layer are similar to the observed "current sheet" [2]. The local poloidal magnetic field nulls the local magnetic pitch through the reconnection process which requires moderate field strength (<100G). Heat transport from the m=1 mode can be accelerated when the reconnection process reaches the outermost surface of the m=1 mode along the magnetic pitch of the q=1 surface. This process is similar to the magnetic reconnection process of the two layers of magnetic surfaces that have the same direction.

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MHD Studies in JET Hybrid Plasmas with Electron Heating

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Experiments in the hybrid scenario of tokamak operation have demonstrated the possibility of attaining high plasma beta with high confinement quality and tolerable levels of MHD activity. The key distinguishing feature of the hybrid regime is a broad q-profile with $q_{min}\approx 1$. Hybrid regimes were explored so far almost exclusively with NBI heating. Sawteeth were either absent or very small, while small-amplitude tearing modes or fishbones were almost ubiquitous in these experiments. Preliminary experiments on electron heating in the hybrid regime have been performed at JET [1] by injecting up to 10 MW of ICRH (51 MHz, H-minority) in hybrid discharges with B=3.2 T and $1.9<I_p<2.6$ MA ($5.6>q_{95}>3.8$). The main observations, partly reported in [2], can be summarised as follows.

- The $q \approx 1$ region features m=1, n=1 modes evolving in very slow relaxation cycles that leave peaked T_e profiles. These modes appear as low-shear-weakened internal kinks.
- Ellipticity-induced Alfvén eigenmodes (EAE) in the q=1 gap are associated with (1,1) oscillations. EAE frequency slightly changes across (1,1) evolution cycles.
- A few fishbones with wide frequency span (from 100 kHz to 10 kHz) are observed at the beginning of main heating.
- TAE and (3,2) or (4,3) NTMs are systematically observed. NTMs appear well before the onset of (1,1) modes. TAE are insensitive to (1,1) evolution cycles, showing that the latter have negligible effects on fast ions.
- ELMs are very weak, in spite of the fact that heating power is well above the H-mode threshold and energy confinement exceeds the values predicted by H-mode scaling.

In this paper the growth rate of the m=1 mode will be studied as a function of q_{95} and l_i and it will be compared to theoretical estimates. The possibility that time-asymmetric (slowly growing and quickly disappearing) m=1 mode pulsations give rise to dynamo effect will be addressed. EAE identification will be reported; EAE frequency evolution will be used as an indicator of q-profile evolution during m=1 cycles.

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Progress on indirect drive target design for the Laser Mégajoule Facility

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The Laser Mégajoule (LMJ) facility is under construction and will deliver up to 2 MJ of 0.35 μm light in 240 beams. Four similar beams are now available on the Ligne d'Intégration Laser (LIL) facility, and the first LIL plasma experiments were completed this winter. On this paper, we will focus on LMJ design studies in indirect-drive configuration.

Different capsules with CH[Ge] ablator are studied. Laser plasma instabilities will be smaller in 250 eV targets whereas 350 eV capsules will be more tolerant to initial roughness. A global model enables us to minimize these risks inside the possible laser domain. Our nominal design A1040 has similar margins regarding these two uncertainties. LMJ ignition studies aim to quantify more precisely these risks with specific codes and experiments on Omega and LIL facilities.

2D-hydrodynamic instability simulations were performed with different CH and DT roughness. Sensitivity of hydro instability growth to DT gas density, which depends on the cryogenic temperature, is evaluated with a 1D-mixed model. The same target, with graded dopant instead of uniform one, is less sensitive to ablator roughness.

Low mode deformations of the DT shell are estimated at maximum velocity. The main causes of deformation are CH thickness defects for modes 1-2 and intrinsic X-ray non-uniformities for modes 4-10. Effects of random errors as laser mispointing, imbalance and hohlraum geometrical defects are fewer, according to LMJ specifications.

Intrinsic and random radiation asymmetry due to a tetraedrical hohlraum compatible with direct-drive configuration (beams at angles of 49° from the vertical shifted at 78°) has been estimated. The comparison of second and third harmonic light potentialities is in progress.

Theoretical description of high order harmonic propagation in overdense relativistic plasmas

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A set of high order laser harmonics (7<n<13) has been measured at the front and at the rear side of a thin foil target under conditions of a high intensity short pulse irradiation (up to 10^{20} W/cm^2) [1]. Contrary to the conditions of Ref. [2] hydrodynamical simulations of the laser prepulse plasma interaction have shown heating and expansion of the target to subcritical densities for the measured subset of harmonics. We present theoretical model of harmonic propagation through relativistic dense plasma motivated by these observations. Spectral properties of the transmitted light display significant broadening, shift and fine structure as compared to the reflected light spectra. These features are explained by the time variation of the index of refraction due to increasing relativistic electron density and the growth of a magnetic field. The index of refraction for the magnetized plasma with the relativistic electron population is analyzed. Contributions of different polarizations to the harmonic spectra are examined in the context of the generation mechanism due to critical density oscillations and the effect of a magnetic field. Comparison between intensities of reflected and transmitted harmonic signals allows for the estimate of collisional and/or anomalous absorption in the plasma and the measurement of anomalous resistivity in overdense plasma. Seeding of the free-electron laser like instability by propagating harmonics is also discussed.

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Powerful terahertz emission from a laser wakefield in inhomogeneous underdense plasma through linear mode conversion

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Abstract

Powerful coherent emission around the plasma oscillation frequency can be produced from a laser wakefield through linear mode conversion. This occurs only when the laser pulse propagates obliquely against a positive plasma density gradient. The emission spectrum and conversion efficiency are obtained analytically, which are in agreement with particle-in-cell simulations. The energy conversion efficiency from laser pulses to this low-frequency emission, which scales proportional to the incident laser intensity like I_L^2, can be as large as 5x 10^{-4} at $I_L\lambda^2$=3.4x 10^{17}W/cm^{2}μm^2. The emission can be tuned to be a radiation source in the terahertz (THz) region and with field strengths as large as a few GV/m, suitable for high-field applications. The emission also provides a simple way to measure the wakefield amplitudes, crucial for the laser wakefield accelerators. Moreover, it can provide a judgement whether plasma wave-breaking occurs or not since the resulting emission is different between the two cases.

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Brilliant Highly Directive Higher Harmonics and Soft X-Ray Lasers from Solid Target Plasma Pumped by Tabletop Ti:S Laser

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We demonstrate the generation of up to the 63rd harmonic (12.6 nm) of a Ti: sapphire laser pulse (150 fs, 10 mJ), using prepulse (210 ps, 24 mJ) produced boron plasma as the nonlinear medium. The influence of various parameters on the harmonic conversion efficiency was analyzed. The steep decrease of the intensity for low-order harmonics (up to 19th order) was followed by a plateau [1]. Typical conversion efficiencies were evaluated to be between 10^{-4} (for third harmonic) and 10^{-7} (within the plateau region). Harmonic generation appeared to be efficient in the case of the plasma consisted on neutral atoms and singly ionized boron. Typical divergence was found as small as 0.2 mrad. The strong 13th harmonic radiation (61.2 nm) with output intensity almost 60 times higher than neighbor harmonics and conversion efficiency of $6x10^{-5}$ was observed in the case of indium plasma. The main contribution to the limitation of harmonic generation efficiency and cutoff energy was caused by the self-defocusing of main beam. Spectral measurements showed that the high conversion efficiency of 13th harmonic was caused by resonance enhancement of nonlinear susceptibility of indium plasma in the vicinity of 61 nm. So far, we have demonstrated new scheme of 18.9-nm soft x-ray laser in Mo plasma [2]. Results of current studies of high-order harmonic generation and soft x-ray lasers will be reported together with characteristics of newly developed 30 fs, 20 TW advanced Ti:S tabletop laser.

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