

Making waves with 3-D external magnetic fields in high temperature plasmas

New techniques to trigger edge plasma relaxations on demand with 3-D magnetic fields, and to image the resulting surface-wave phenomena with synchronized super-fast cameras, have been developed in the National Spherical Torus Experiment to better understand and use controlled edge relaxation events to remove impurities.

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Plasmas confined with magnetic fields are externally heated to simulate the necessary conditions for thermonuclear fusion. The efficiency by which plasmas can retain the heat input is measured by the energy confinement time. In the early 1980's a new mode of operation was discovered in which the energy confinement time was observed to spontaneously double; this mode was termed 'H-mode' for high confinement mode. A common observation in H-mode discharges was that the plasma showed signs of periodic relaxation events, which were named Edge Localized Modes or ELMs. These ELMs ejected impurities from the edge plasma region, preventing buildup of contaminants and helping to control the plasma density. When imaged with visible cameras, these ELMs were shown to consist of spiraling, ribbon-like filaments, similar in appearance to surface waves in hydrodynamics. The negative aspects of these ELMs include a small reduction of energy confinement, and periodic heat pulses to the plasma-facing components (PFCs). These heat pulses are a concern for future fusion devices if the individual ELMs each result in a substantial loss of the plasma stored energy, leading to a large heat pulse and possible PFC damage. On the other hand, H-mode discharges without ELMs (termed ELM-free H-mode) were shown to be transient because both impurities and fuel could not leave the edge plasma, which resulted in an increase in the radiation from the plasma and an eventual thermal collapse as the plasma cooled. Thus having small, frequent ELMs to provide impurity ejection without large heat pulses could be one operational mode for future reactors.

In the National Spherical Torus Experiment (NSTX), several innovations are being combined to obtain new insight into the physics of ELMs, and these innovations will be presented in a series of talks at the 2008 APS Division of Plasma Physics conference. The ultimate goal is to develop operational scenarios with small, rapid ELMs. First, the PFCs inside NSTX were coated with lithium from specially designed ovens placed in the vacuum chamber. While the lithium improved energy confinement, it also somewhat surprisingly

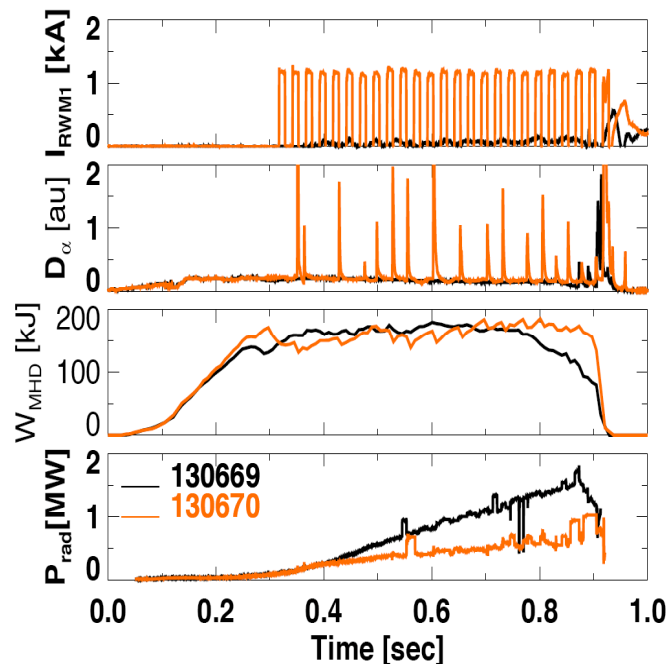


Fig. 1 – reference ELM-free discharge (black) and ELMy discharge (orange) where the ELMs were triggered with short pulses of 3-d fields.

suppressed the ELMs, which were present in pre-lithium discharges. However this ELM-free H-mode then suffered from impurity build-up. To fix this, a pulsed 3-D magnetic field was imposed using a set of coils just outside the vacuum vessel, to magnetically trigger ELMs. This pulsed magnetic field is in addition to the magnetic field used to confine the plasma. The added magnetic field was in the radial direction and varied around the plasma, with three sinusoidal periods around the plasma circumference. The technique was successful: the magnetic field was used to ‘make waves’, flush impurities, and improve the discharges. Fig. 1 shows the 3-D field pulses (I_{RWM1}) in panel (a); ELMs are evident as sharp spikes in the edge light (D_{α}) emission in panel (b); the time-averaged plasma stored energy (W_{MHD}) is comparable in panel (c); and radiation from plasma impurities (P_{rad}) is reduced in panel (d).

The second innovation involves diagnosis of the ELM movement. Commercial fast cameras are now capable of unprecedented speeds of more than one hundred thousand frames per second, as compared with 60 frames/second for traditional consumer-oriented video cameras. Two such cameras have been deployed on NSTX and time synced; one views the entire plasma cross section with a wide-angle lens at the midplane, while the other focuses in a 25 cm square region near the plasma edge. With these two synced cameras, the motion of the ELM filaments can be clearly tracked in three dimensions, and the difference between primary filaments (the ones originating from the ELM) and secondary filaments (the ones driven by the plasma response to the ELM) can be clearly distinguished. The explosiveness of these ELM filaments is shown in figure 2: this particular ELM consists of many filaments that exploded outward from the periphery.

The combination of these two innovations to create high performance plasmas with magnetically triggered ELMs-on-demand, and to diagnose the details of the ELM evolution, are helping to further optimize the plasmas in NSTX.

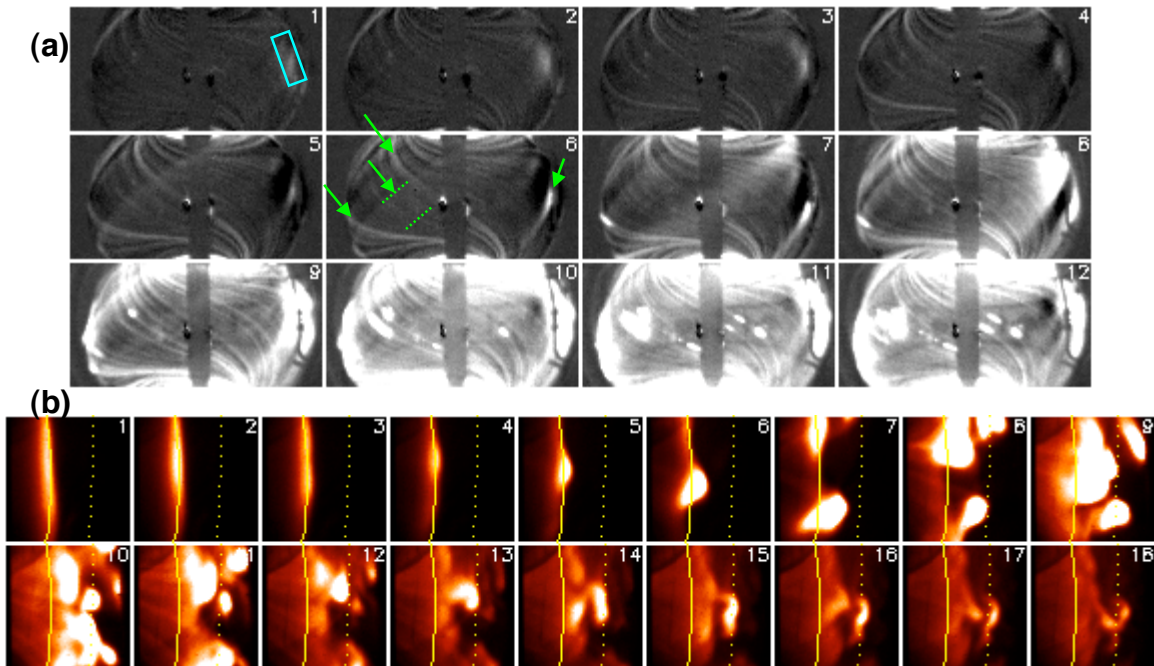


Fig. 2 – Images of a giant ELM taken by synced, super-fast video cameras. The upper panels are from the wide-angle view and the lower panels from the focused view at the plasma edge. Many filaments can be observed. The time between frames is 8.2 μ s, and the view of the focused camera is highlighted by the blue box in upper panel #1.

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