Recent progress and upgrade plan of KTX reversed field pinch

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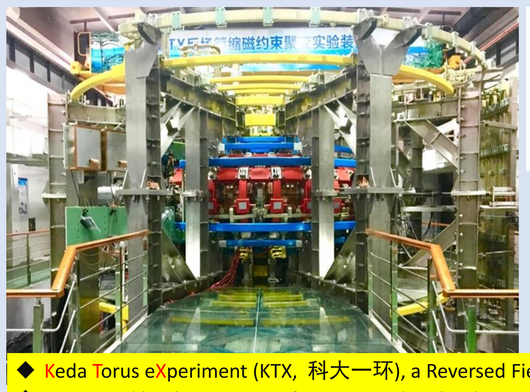
Keda Torus eXperiment

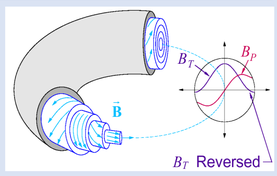
ABSTRACT

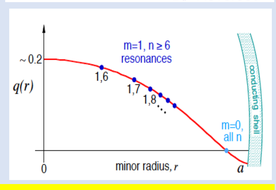
Recent works on Keda Torus eXperiment (KTX) focused on operation capabilities upgrade. The upgrade design details of the main ohmic power supply, the equilibrium field power supply and the edge active feedback control system have been completed. The electronic system and fast control power supplies of the active feedback control system are under test. The capacitor banks and switching elements of the main power supply for upgrade have been put into production. Advanced diagnostics for 3D physics research, including the terahertz interferometer, Thomson scattering system, double-foil soft x-ray imaging, edge capacitive probe and multi-channel spectrograph system, have been developed for the normal operation and physical analysis at present stage. Based on the present power supply system, the maximum plasma current can reach 300kA and the during time of reversed field pinch state is approaching 3ms. Magnetohydrodynamic (MHD) activities in the ultra-low safety factor configuration are investigated experimentally to explore the plasma self-organization phenomena on KTX device in the current state of operation. The characteristics of various quasi-single helicities (QSHs) in KTX are also investigated in ideal MHD simulations with helical equilibria.

BACKGROUND

- The Keda Torus eXperiment (KTX) is a new built middle-size reversed field pinch (RFP) device at the University of Science and Technology of China. The mission of KTX is complementary to the existing international Revered Field Pinch (RFP) facilities. The plasma wall interactions, transport in different boundary conditions, the single helicity (SH) state are the main physics aspects of KTX. The wall condition has been optimized for higher plasma parameters, including plasma current and discharge period. Advanced diagnostics, including the terahertz interferometer, Thomson scattering system, double-foil soft x-ray imaging, edge capacitive probe and multi-channel spectrograph system, have been developed for the normal operation and physical analysis at present stage.







- Keda Torus eXperiment (KTX, 科大一环), a Reversed Field Pinch
- Supported by the Ministry of Science and Technology, in the framework of the ITER domestic program

CHALLENGES / METHODS / IMPLEMENTATION

- Small externally applied field: the use of normal magnets, high engineering beta, high mass-power-density, efficient assembly
- Large plasma current density: Ohmic heating for a burning plasma
- Self-organized state: Disruption free
- Fascinating phenomena of self-organization and nonlinear plasma physics: test bed for the understanding derived at high field, good platform to investigate the transport, link between the fusion energy science and astrophysics

Why to build a RFP device at USTC, China

- **Related to fusion energy research:** RFP is an alternate of tokamak configuration, an important direction to explore further RFP configuration for MCF
- **Related to ITER:** Some important ITER physics, e.g. RWM (high beta, long pulse), MHD control, chaotic edge magnetic field
- **Related to astrophysics and space physics:** Magnetic reconnection, Dynamo, anomalous ion heating, moment transport
- **An important facility for basic research and education:** Campus size platform for high temperature fusion plasma physics: easy operation, disruption free, without additional heating

Main parameters

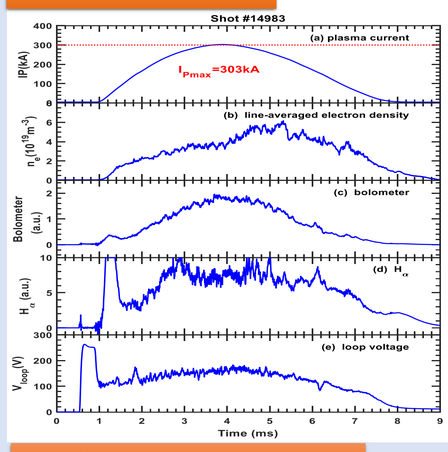
Major radius	1.4 m
Minor radius	0.4 m
Thickness of vacuum shell (SS)	6 mm (τ ~ 2ms)
Thickness of conductive shell (copper)	1.5 mm (τ ~ 20ms)
Plasma current	0.5MA (Phase I), 1.0 MA (Phase II)
Pulse length	30 ms (Phase I), 100 ms (Phase II)
Loop voltage	20 ~ 100 V
Plasma inductance	~ 3 μH
Total magnetic flux	3 ~ 5 V·S
Electron temperature	600 ~ 800 eV
Plasma density	~ 10^{19} m^{-3}
Maximum toroidal field	7000 Gauss

Future work

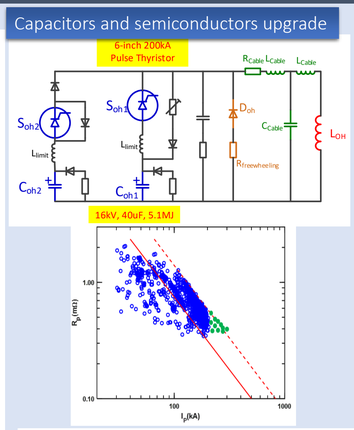
- **To achieve 500kA/10ms (~40ms *RFP* state) high temperature plasmas**
  - KTX enters the high-parameter operation state, realizes the quasi-single helical state and other plasma with typical three-dimensional characteristics, and the plasma current reaches 500kA.
- **Application of active control technology**
  - Built the active control system on KTX, to improve the plasma confining performance
  - The discharge time of KTX can reach 100ms
- **Understanding three-dimensional physics of reversed pinch**
  - Explore and understand the common and intrinsic mechanisms of instability, plasma turbulence and density limits of KTX
  - KTX reverse field pinch configuration time reaches 40ms

Improvements of KTX capability

Plasma current > 300kA

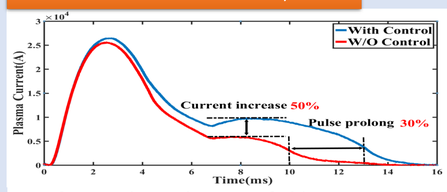


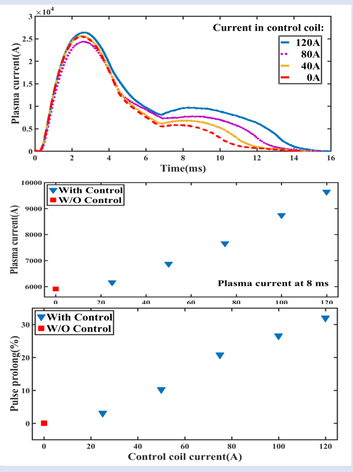
Capacitors and semiconductors upgrade



The maximum current of **300kA** is achieved via discharge operation optimization.

Error field active control system

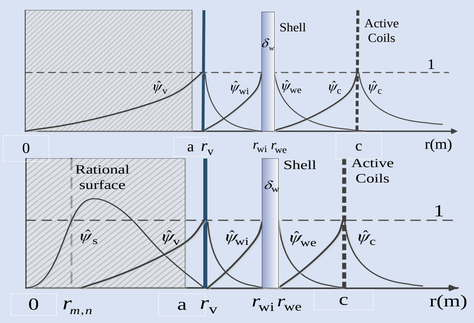




- After applying the error field active control, plasma current increases by **50%** during the platform phase, Pulse duration increased by **30%**.
- Within the capability of the power amplifier, it is verified that the error field active control system can effectively improve the plasma discharge time.
- The efficiency increases monotonically with the added current.

Three-dimensional plasma physics

Simulations on KTX instability active control

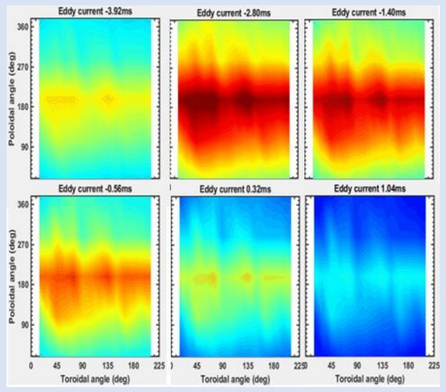


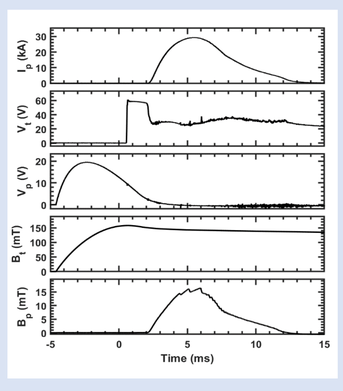
Tearing mode

Solve the fluid equations with respect to the toroidal and polar angular velocity under the condition of the electromagnetic force equilibrium generated by the viscous torque and the tearing mode.

Resistive Wall Mode

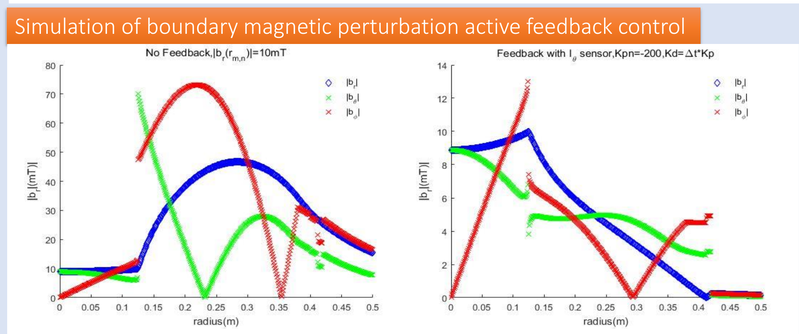
Given initial conditions, consider the modes growth with no feedback and the stabilization or rotation with feedback.





- For the first time, the time evolution of the two dimensional local eddy currents in the shell along the toroidal and poloidal directions is given experimentally with eddy current probe arrays.

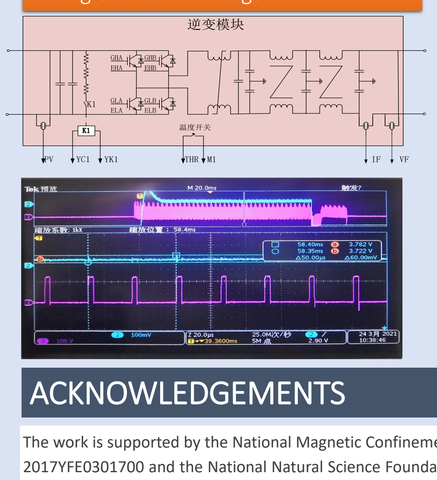
Simulation of boundary magnetic perturbation active feedback control



The plasma active control simulation is applied under KTX geometry, and the eddy current probe array is used as important input controlling parameters to verify the feasibility of KTX active control.

Fast control power supplies for active control coils

Realization of low current ripples under strong excitation voltage



In the given current flat top section of 100A DC, the output current is 99.25-100.85A, and the corresponding current accuracy is 0.85A, which meets the requirement of current accuracy 1A.

At a given DC of 100A, the signal is a voltage signal directly measured by the differential probe, and the output voltage is a square wave pulse signal with an amplitude of 200V and a frequency of 1/25μs=40kHz, which satisfies the requirements of output voltage of 200V and output frequency of 0.1-1kHz.

ACKNOWLEDGEMENTS

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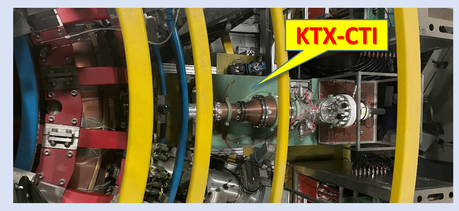
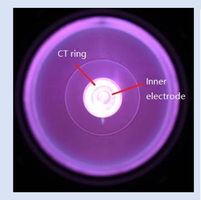
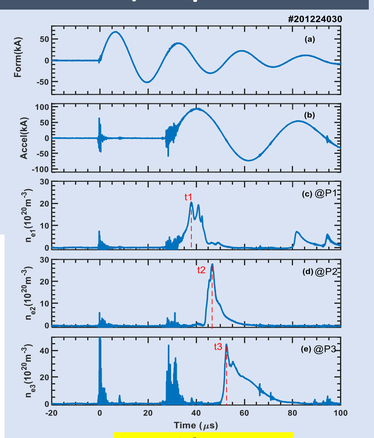
Compact torus injection (KTX-CTI) experiment





Compact torus image

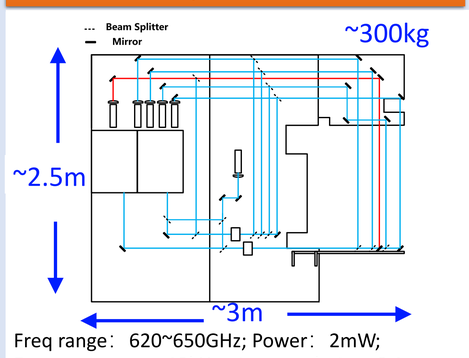
Understanding magnetic helicity transport is essential for RFP plasma studies. In addition to upgrading KTX capability, we hypothesized that the CT injection might improve the plasma performance and realize a prolonged RFP state due to helicity and tangential momentum injections.



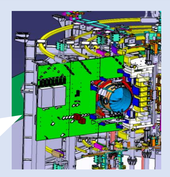
$$\bar{v}_{CT} = \frac{\Delta d}{\tau_{delay}} > 100\,\mathrm{km/s}$$

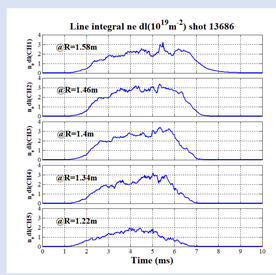
Diagnostics for three-dimensional plasma physics

Development of a 5-channel terahertz solid-source microwave polarization interferometer

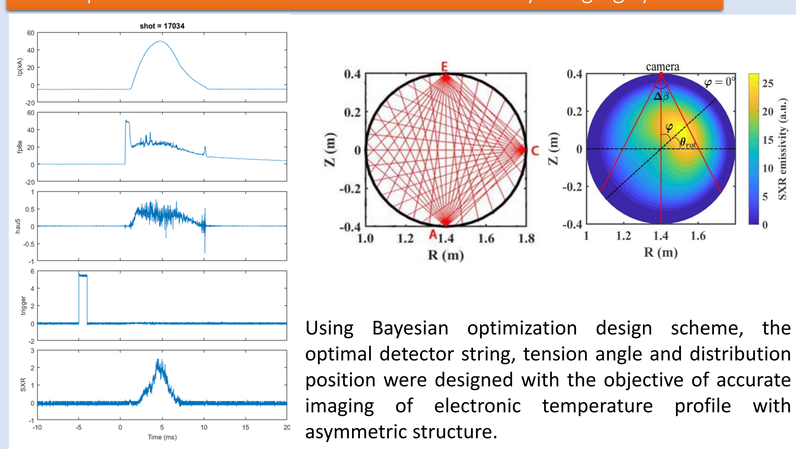


Freq range: 620~650GHz; Power: 2mW;
Freq accuracy: ~13kHz; time resolution: 0.1us.



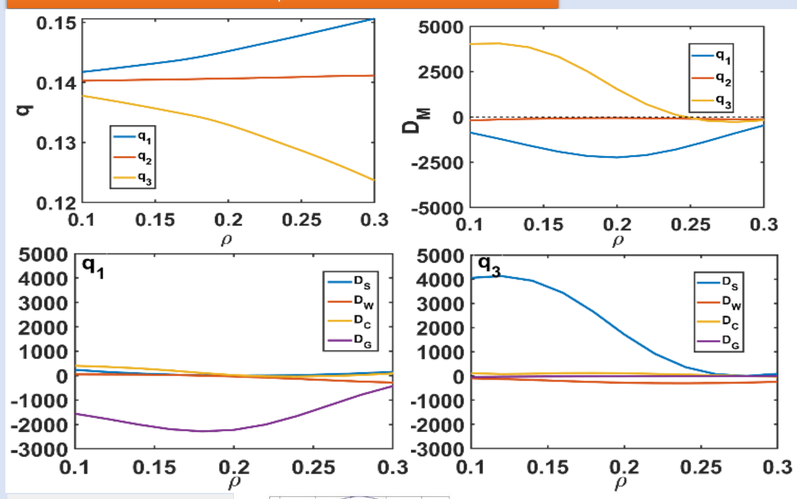


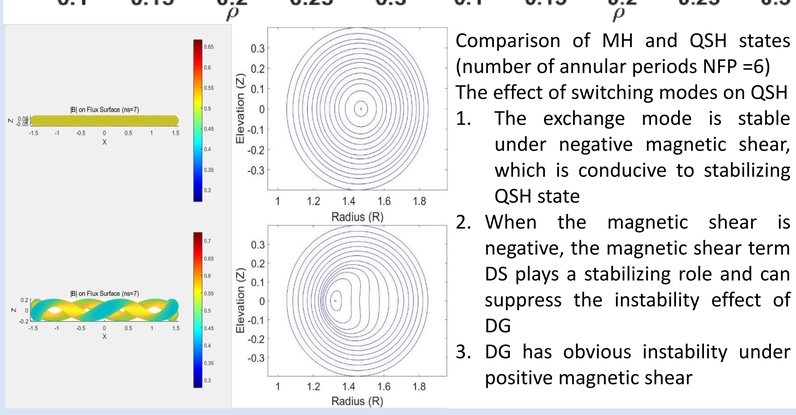
Development of 320-channel double-foil soft x-ray imaging system



Using Bayesian optimization design scheme, the optimal detector string, tension angle and distribution position were designed with the objective of accurate imaging of electronic temperature profile with asymmetric structure.

KTX three-dimensional equilibrium studies





Comparison of MH and QSH states (number of annular periods NFP =6)
The effect of switching modes on QSH

1. The exchange mode is stable under negative magnetic shear, which is conducive to stabilizing QSH state
2. When the magnetic shear is negative, the magnetic shear term DS plays a stabilizing role and can suppress the instability effect of DG
3. DG has obvious instability under positive magnetic shear

Summary

- ☆ **The upgrading of KTX operation capacity is in progress. The optimized Ohmic field power supply achieved plasma discharge current over 300kA. In the mean time, the power supply designs for equilibrium field coils and active feedback control system have been completed.**
- ☆ **The diagnostics for 3D plasma physics research are prepared, including the 3D double-foil soft X-ray array, Langmuir probe array, eddy current array and 5-channel solid-state source Terahertz interferometer/polarimeter. As well, the 3D equilibrium code for KTX is ready.**
- ☆ **The simulations for QSH/SH are also developing on KTX.**
- ☆ **All the upgrades will be completed in the end of 2022.**

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