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A scalable real-time framework for Thomson scattering analysis: Application to NSTX-U

F. M. Laggner¹, A. Diallo², B. P. LeBlanc², R. Rozenblat², G. Tchilinguirian², E.Kolemen¹ and the NSTX-U team

¹Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey, USA ²Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA

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Motivation - Real-time (rt) profile measurements for advanced plasma control

- Real time (rt) Thomson scattering (TS) beneficial for
 - Rt equilibrium reconstruction (rt-Efit) with pressure constraint
 - Rt profile availability for control purposes
 - ELM control (timescale ~ 10 ms)
 - Core transport (timescale > 10ms)
 - Resistive wall mode (timescale ~ 1 ms)
- Rt-upgrade of the existing TS diagnostic at NSTX-U
 - Rt capable data acquisition (hardware)
 - Rt TS analysis (software)
- Develop a prototype 'small' system that is scalable
 - Demonstrate rt capability of data acquisition and TS analysis

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[E. Kolemen, et al., IAEA FEC, 2016]

Setup of the multi point Thomson Scattering (MPTS) diagnostic at NSTX-U – Determines **rt system specs**

Neutral beam

To Beam

dumn

Second neutral beam NSTX-U center stack

8 cm

62.9 cm

Old beam

- Currently two 30 Hz Nd:YAG lasers
 - repetition rate of 60 Hz
 - ~17 ms in between the laser pulses
- Polychromators and avalanche photodiode (APD) detectors
 - 4 or 6 interference filters
 - 6 rt digitizer channels per radial channel
- Post-discharge analysis
 - Current analysis should stay unaffected
- [D. W. Johnson, et al., RSI, 2001] [B. P. LeBlanc, et al., RSI, 2012]
- [B. P. LeBlanc, et al., RSI, 2003] [A. Diallo, et al., RSI, 2012] [D. J. D. Hartog, et al., JINST, 2017]

Collection Optics box

G

MPTS at NSTX-U measures **T**_e and **n**_e **profiles** across the full plasma cross section

- Prototype rt TS
 analysis framework
 - 8 radial channels
 - Measures electron 0.5 temperature (T_e) and electron density (n_e) \$\vec{1}\$0.0
 - Independent of
 Plasma Control
 System (PCS)
 servers
 - Analysis performed on separate rt server



Rt hardware setup – Commercially available electronics utilized and designed to scale towards larger system



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SuperMicro RT server

Struck SS3316

Rt-ADC capable of **sampling the full signal pulse** – Previously used CAMAC digitizes only 1 point



- Currently only pulse peak amplitudes (PA) used for analysis
- Advanced pulse fitting could be done
 - Better amplitude estimation at low signal levels
 - Deconvolving amplifier response function from detected signal

Rt-software – Streamlined analysis workflow in C++ that offloads expensive calculations before the discharge

- Full MDSplus storage
 - Calibrations, raw data and analyzed $T_{\rm e}$ and $n_{\rm e}$
- Continuous data acquisition
 - Circular buffer
 - Analysis triggered by TS laser pulse
- Analog output

[R. Rozenblat, et al., FED, in prep.]



Analysis speedup achieved - Pre-computation of expected signal intensity (lookup table)



Used to detect the TS spectrum

- Calculation of expected intensity at each spectral channel
 - Variation of $T_{\rm e}$ from 0 to 10 keV and storage in lookup table
 - Rt-process compares measurement and expectation and determines best T_e

Rt analysis 10 times faster than post shot calculation -Excellent agreement of results from both methods



of analysis from different radial channels

- Scales favorably to higher amount of radial channels (analysis time still 2.5 ms)
- End to end processing time of <17 ms achieved (for \sim 30 min)

[F. M. Laggner, et al., RSI, in prep.]

Summary - Successful implementation of rt TS analysis

- Real-time prototype system for TS analysis designed, developed and offline tested
 - New rt hardware and software
 - Framework could be also used at other diagnostics
 - Scalable, reliable and deterministic setup



- Benchmark of rt analysis against post shot analysis code
- System meets a 60 Hz laser pulse deadline for 30 min
 - Applicable to TS systems of long pulse machines

Outlook – Deployment at the large helical device (LHD)

- LHD needs rt TS system
 - n_e profiles in long pulse operation with ECH to track density cutoff
 - Intended use as important system for machine protection



- Rt TS as sensor for advanced plasma control
- Benefit for NSTX-U
 - Experience for routine system operation will be gained
 - Ready to go after the recovery period

– Speed-up possible: Upgrading rt-ADC firmware and code optimization[®]