A review of Machine Learning-driven tearing studies for disruption prediction

Recent advancements [1] have demonstrated the efficacy of machine learning (ML) techniques in predicting and controlling tearing modes – magnetohydrodynamic (MHD) instabilities that can degrade plasma confinement and lead to disruptions – in tokamak plasmas. These studies leverage extensive experimental data and sophisticated ML algorithms to enhance plasma stability and performance. Additionally, the threat of tearing modes has driven for years research under the International Tokamak Physics Activity (ITPA) MDC-22 topic, aiming at designing a successful trigger for ITER's disruption mitigation system [2, 3]. In this contribution, we present the ongoing challenge and summarize the latest achievements for identifying the path to stable operations in ITER and beyond. Results presented will include both experimental analysis [4-8] investigating the role of differential rotation and of current profile evolution, and modeling of linear and nonlinear trends [9,10], to inform how to maximise passive resistance to island formation for reactor relevant scenarios.

References:

[1] J. Seo et al. Avoiding fusion plasma tearing instability with deep reinforcement learning. Nature 626, 746–751 (2024). https://doi.org/10.1038/s41586-024-07024-9

[2] E.J. Strait *et al* 2019 *Nucl. Fusion* **59** 112012 doi:10.1088/1741-4326/ab15de

[3] I. Bandyopadhyay et al 2025, MHD, Disruptions and Control Physics, Chapter 4 of the Special Issue: On the Path to Tokamak Burning Plasma Operation, under review

[4] L. Bardoczi *et al Phys. Plasmas* 30, 092505 (2023) doi:10.1063/5.0165859

[5] L. Bardoczi *et al* 2024 *Nucl. Fusion* **64** 126005 doi:10.1088/1741-4326/ad7787

[6] K.E.J. Olofsson et al. J. Plasma Phys. (2022), vol. 88, 895880503

[7] K E J Olofsson et al 2018 Plasma Phys. Control. Fusion 60 084002

[8] Y. Fu et al *Phys. Plasmas* 27, 022501 (2020) doi:10.1063/1.5125581

[9] S Benjamin *et al* 2024 *Plasma Phys. Control. Fusion* **66** 075016 doi:10.1088/1361-6587/ad4e68

[10] S Benjamin *et al* 2025, manuscript in preparation

Should this be referenced: F. Turco *et al* 2024 *Nucl. Fusion* **64** 076048
doi:10.1088/1741-4326/ad518e
I have asked Andy Rothstein if his recent work ‘Preemptive tearing mode suppression using real-time ECH steering machine learning stability predictions on DIII-D’ has been published

Notes:

- https://ecmrp2.sciencesconf.org/?lang=en

- pubblico teorico, che ha però molto interesse anche nei dati sperimentali, invitation based on:

- https://iopscience.iop.org/article/10.1088/1361-6587/ad4e68/pdf
  Macroscopic trends of linear tearing stability in cylindrical current profiles
  S Benjamin3,1, C Clauser1, C Rea1, R Sweeney2, A Kumar1 and E Marmar1
  2024 PPCF

- https://iopscience.iop.org/article/10.1088/1741-4326/ad7787
  The root cause of disruptive NTMs and paths to stable operation in DIII-D ITER baseline scenario plasmas
  L. Bardoczi1,2,*, N.J. Richner3, N.C. Logan4,5, E.J. Strait1, C.T. Holcomb4, J. Zhu6 and C. Rea6 2024 *Nucl. Fusion*

- https://pubs.aip.org/aip/pop/article/30/9/092505/2909948/Empirical-probability-and-machine-learning
  Empirical probability and machine learning analysis of m, n=2, 1 tearing mode onset parameter dependence in DIII-D H-mode scenarios
  L. Bardóczi; N. J. Richner;J. Zhu;C. Rea;N. C. Logan *2023 Phys. Plasmas*

- https://iopscience.iop.org/article/10.1088/1741-4326/ab15de
  Progress in disruption prevention for ITER
  E.J. Strait1, J.L. Barr1, M. Baruzzo2, J.W. Berkery3, R.J. Buttery1, P.C. de Vries4, N.W. Eidietis1, R.S. Granetz5, J.M. Hanson3, C.T. Holcomb6, D.A. Humphreys1, J.H. Kim7, E. Kolemen8, M. Kong9, M.J. Lanctot17,1, M. Lehnen4, E. Lerche10,11, N.C. Logan8, M. Maraschek12, M. Okabayashi8, J.K. Park8, A. Pau13, G. Pautasso12, F.M. Poli8, C. Rea5, S.A. Sabbagh3, O. Sauter9, E. Schuster14, U.A. Sheikh9, C. Sozzi15, F. Turco3, A.D. Turnbull1, Z.R. Wang8, W.P. Wehner14 and L. Zeng16
  2019 *Nucl. Fusion*