LHC Optics Measurements from Transverse Damper for the High Intensity Frontier

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- LHC Transverse Damper (ADT) can be used in ac dipole-like mode to provide coherent transverse excitations.
- Excitation amplitude is lower compared to ac dipole, but spectral resolution can be improved by increasing number of turns acquired.
- First linear & nonlinear optics measurements with the ADT performed in 2023.

OPTICS MEASUREMENTS WITH THE ADT

- Pilot bunches at injection energy, ADT excitations with 28500 turns
- Good agreement observed in β-beating between ADT and ac dipole for both beams and both planes
- Observed deviation generally within measurement errors of ac dipole measurements

Optics measurements can reliably be done with ADT at injection energy

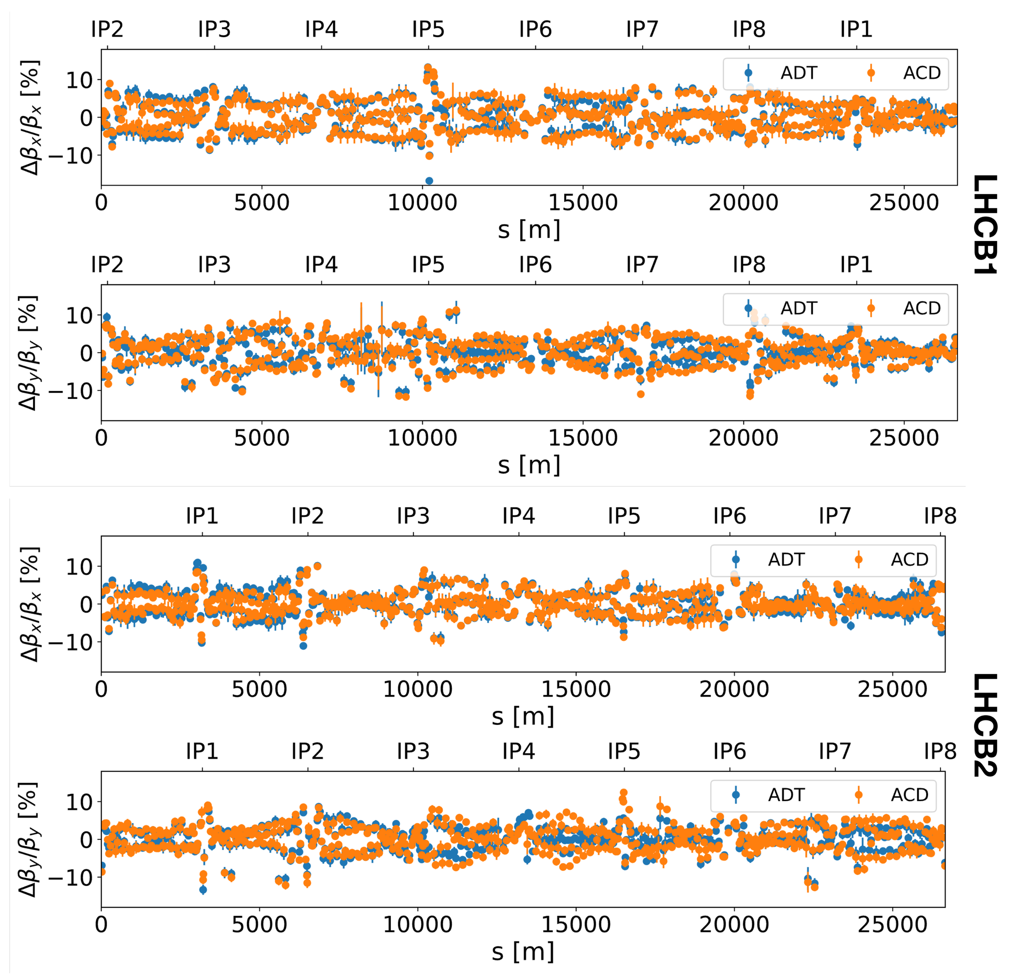

Figure 2: Comparison of Beam 1 (top) and Beam 2 (bottom) horizontal and vertical β-beating between ADT and ac dipole measurements.

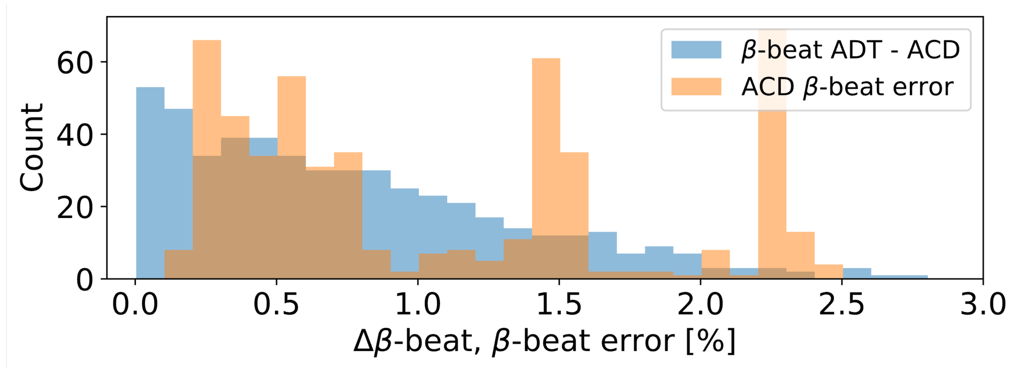

Figure 3: Comparison of difference in β-beating between the ADT and ac dipole measurements and β-beating error for the ac dipole for the horizontal plane of Beam 1.

PHASE RESOLUTION FROM TURN-BY-TURN DATA

- Phase error reduces for increasing oscillation amplitudes
- Higher number of turns decreases the phase error
- Phase resolution of ADT matches with ac dipole at injection energy

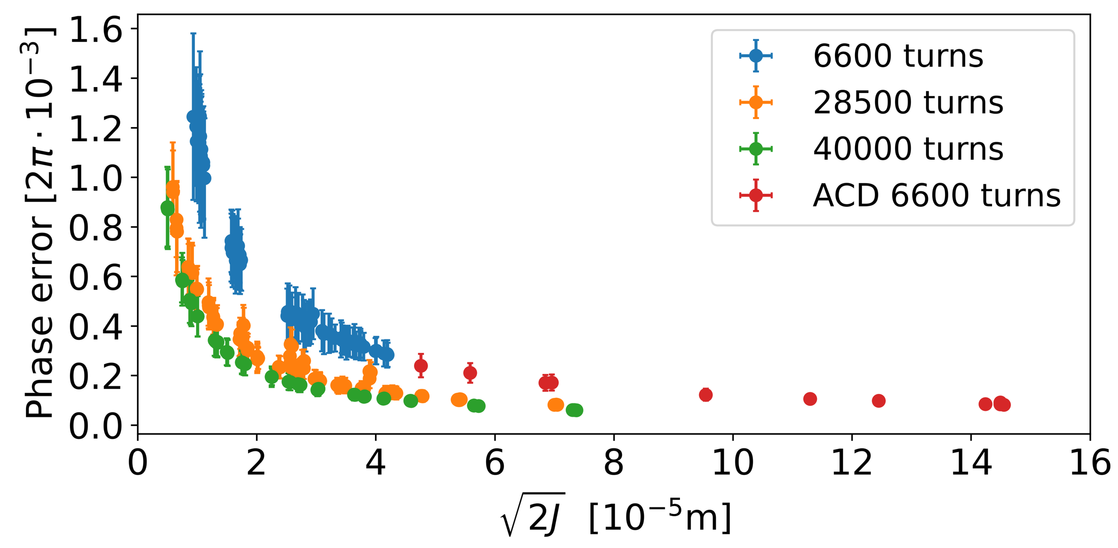

Figure 1: Phase error from ADT and ac dipole excitations as a function of oscillation amplitude for different number of turns.

RESONANCE DRIVING TERMS

- Improved spectral resolution with the increase in turns may benefit measuring resonance driving terms (RDTs)
- Secondary spectral lines $2Q_x^{ADT}$ and $3Q_x^{ADT}$ observed in ADT measurements
- Some qualitative agreement observed between ADT and ac dipole for the sextupolar RDTs
- Promising results for nonlinear optics measurements with the ADT

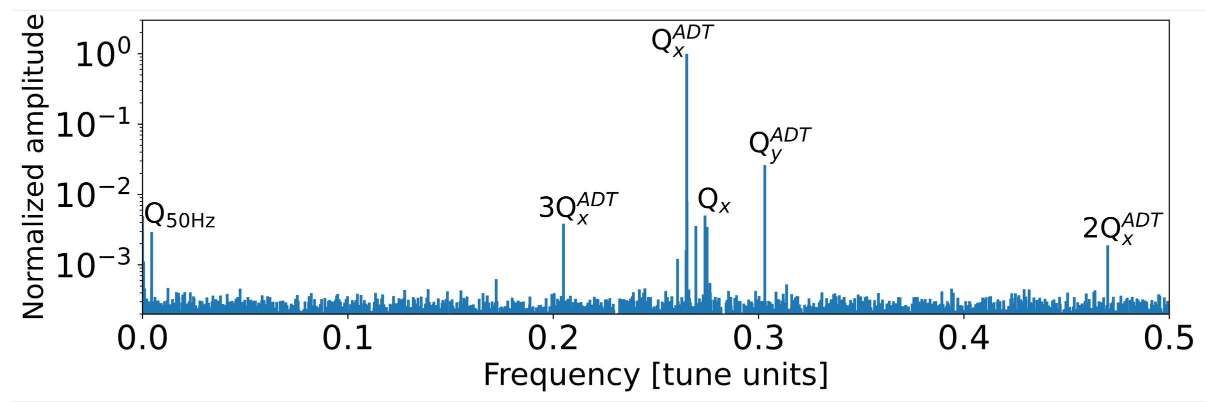

Figure 4: Frequency spectrum of the horizontal plane for Beam 2. Secondary spectral lines are observed at the frequencies $2Q_x^{ADT}$ (normal sextupole) and $3Q_x^{ADT}$ (normal octupole).

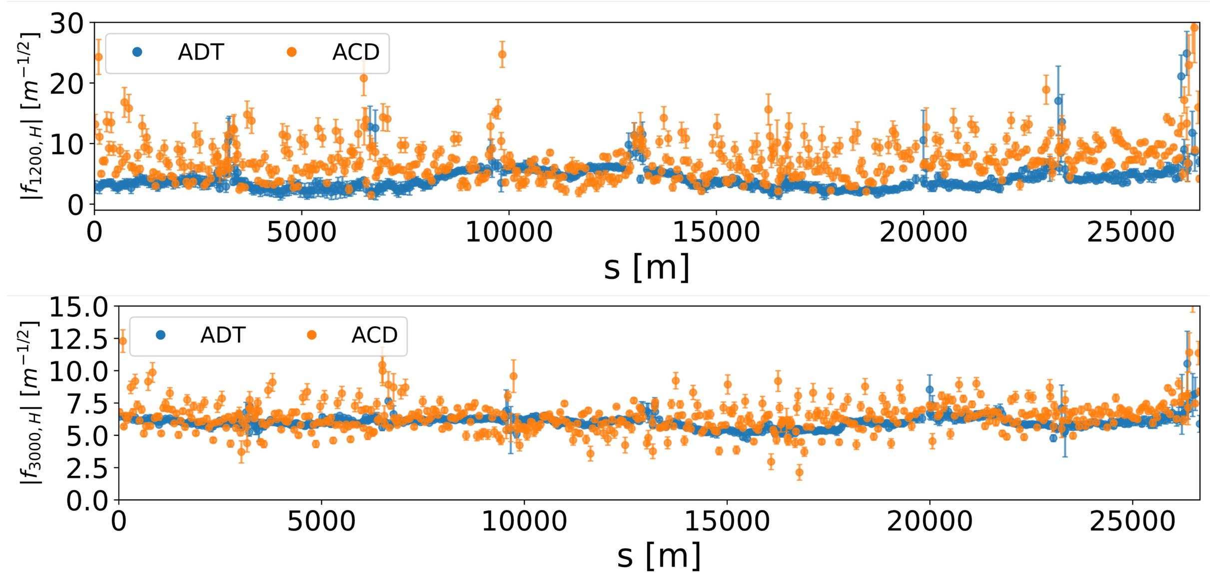

Figure 5: Comparison of normal sextupolar RDTs f_{1200} (top) and f_{3000} (bottom) for Beam 2 between ADT and ac dipole measurements.

OBSERVATION OF 50 HZ SIDEBANDS IN THE ADT

- 50 Hz sidebands observed around the ADT tune at injection energy and at top energy
- Three clear sidebands at frequencies $Q_{x,d} \pm Q_{50Hz}$ and $Q_{x,d} + 2Q_{50Hz}$, $Q_{50Hz} = 4.45\times10^{-3}$
- Likely generated by a 50 Hz modulation of ADT waveform and function as three weaker ac dipoles
  - Amplitude response of the sidebands is asymmetric and increases when approaching the natural tune Q_x
- Relative strength of sidebands with respect to ADT kick strength calculated by treating sidebands as ac dipoles [1]

$$A_p = \frac{B_p}{\sin(\pi(Q_{x,d} + p \cdot Q_{50Hz}) - Q_x)}$$

$B_p = \sqrt{\beta_{ADT}}\hat{B}_p/(4B_0\rho)$ is the effective strength of an ac dipole associated to the pth sideband, $p \in \{-1, 1, 2\}$
$\sqrt{\beta_{ADT}}$ is the β function at the ADT, $\hat{B}_p$ is the integrated magnetic field, $B_0\rho$ is the magnetic rigidity

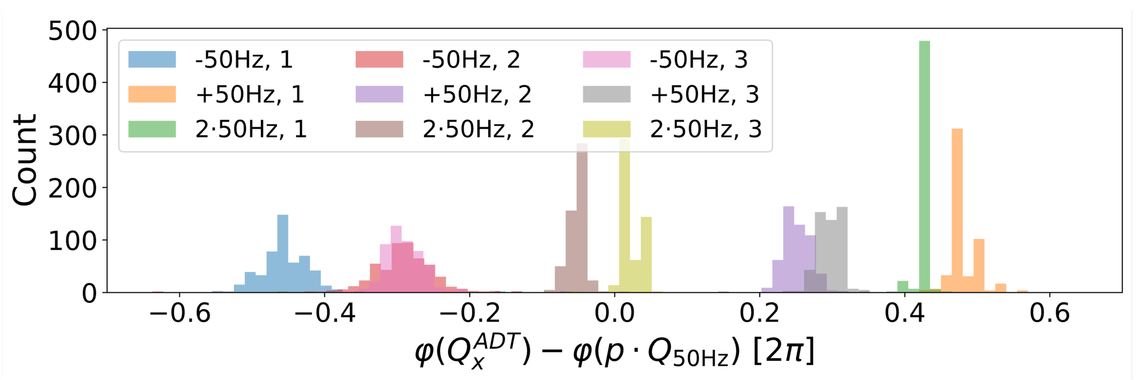

Figure 7: Horizontal phase difference for Beam 1 between ADT and sidebands for three measurements.

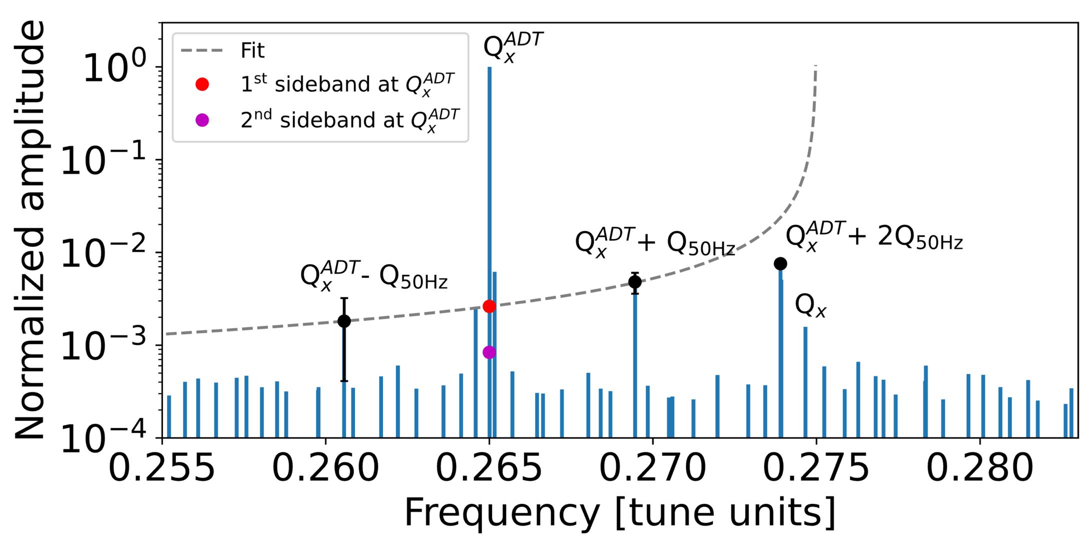

Figure 6: Strength of the 50 Hz sidebands at the frequency of the driven ADT tune for Beam 1.

	1st sideband $[10^{-3}]$	2nd sideband $[10^{-3}]$
B1 H	2.64 ± 0.10	0.85 ± 0.03
B1 V	3.02 ± 0.05	0.90 ± 0.03
B2 H	1.98 ± 0.11	0.57 ± 0.02
B2 V	2.62 ± 0.08	0.41 ± 0.03

Table 1: Measured relative strengths of the 50 Hz sidebands (B_1/B_0 and B_2/B_0) for both beams and both planes.

- Strength of 50 Hz sidebands larger than previously expected, further studies ongoing to determine the effect
- For the first order sidebands, phase difference between the ADT and the sideband is of opposite sign – further analysis needed

CONCLUSIONS

- ADT used for transverse excitations in the LHC with increased number of turns to improve spectral radiation.
- Linear optics measurements agree well with the ac dipole. Increased number of acquired turns could yield fill-by-fill optics measurements at injection.
- First measurements of normal sextupolar and octupolar RDTs with the ADT with promising results for nonlinear optics measurements.
- 50 Hz sidebands observed on the ADT frequency spectrum with a strength of (0.25 ± 0.04)% and (0.069 ± 0.02)% for first and second order sidebands, respectively. Further studies are needed.

REFERENCES

[1] R. Tomás, "Normal Form of Particle Motion under the Influence of an AC Dipole", Phys. Rev. ST Accel Beams, vol. **5**, 54001 (2002).

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HB 2023