LHC Injectors Upgrade

Detection and elimination of the Tune ripple in LEIR

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CERN

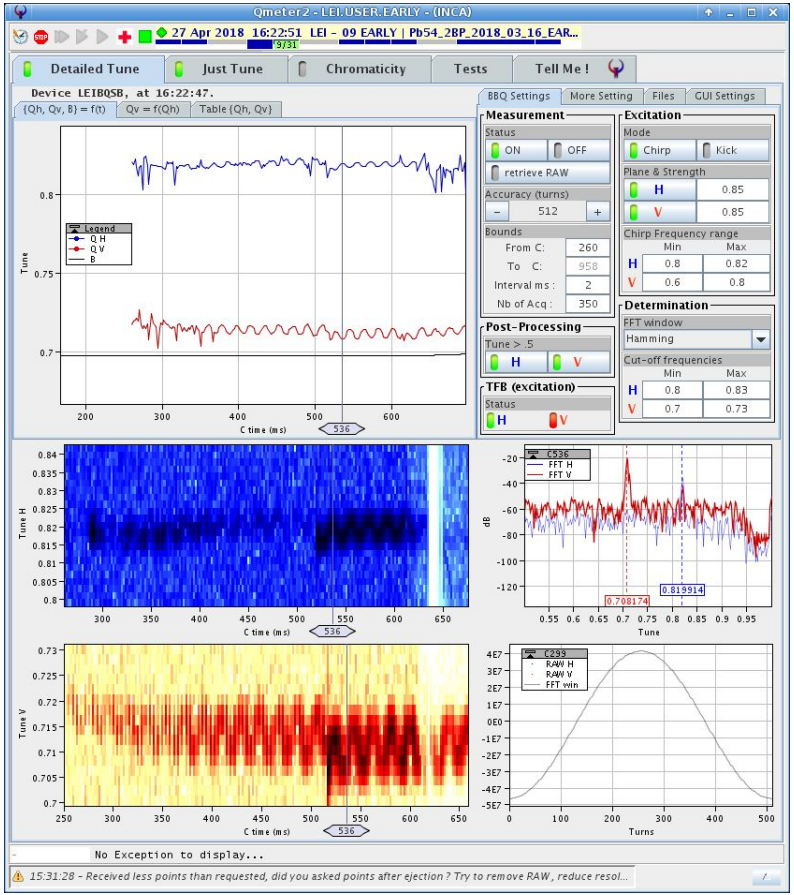
Outlook

1. Illustrate the Tune ripple observed in LEIR (2017)
2. Come up with the cause
3. Measure the signal from the hardware
4. Effect on the extracted beam
5. Possible explanation using Feed-down effect
6. Conclusions

Problem

Using Qmeter2, with a short measuring interval.

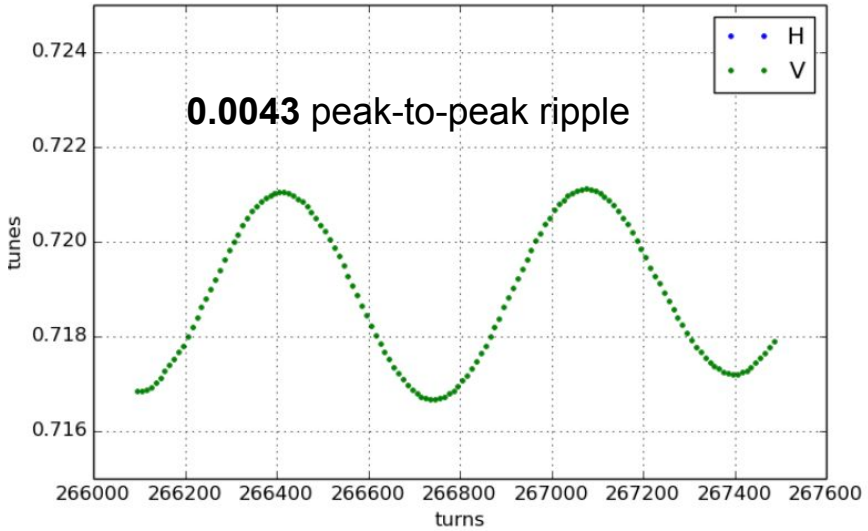
Significant tune ripple observed in LEIR during the second semester of 2017.



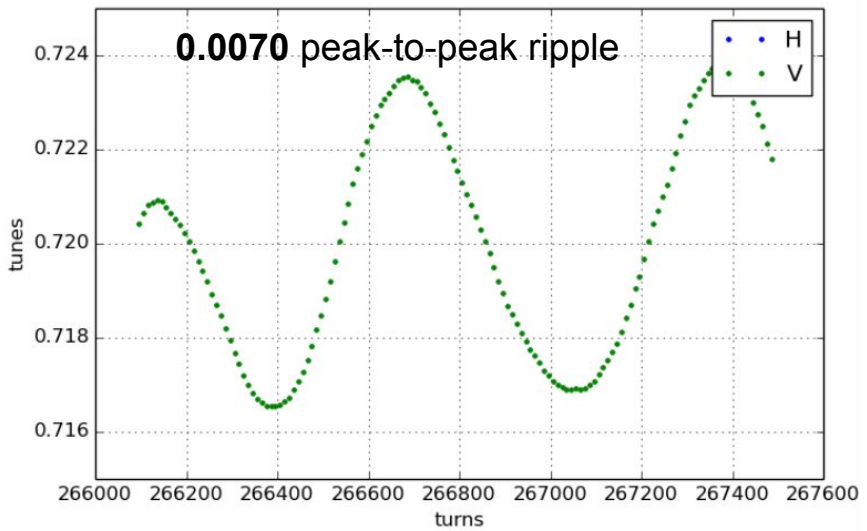
First analysis from the effect on the beam

Analysis from raw signal of the Qmeter: measurements of 2048 turns spaced by 8ms, analyzed in chunks of 256 turns using a sliding window and SUSSIX

30/10/2017



11/12/2017

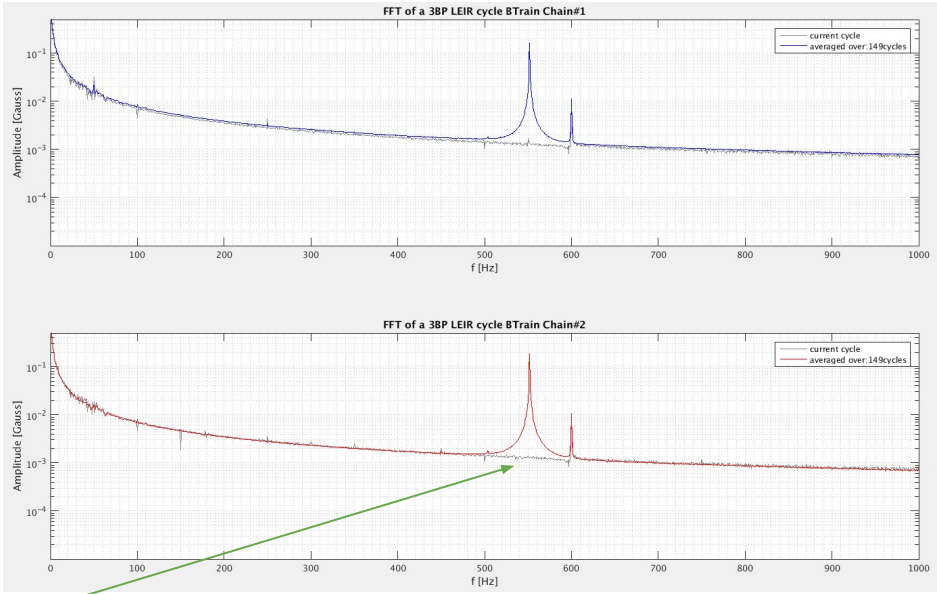


Frequency of around 550 Hz

Investigating the cause:

1. Measure dipole field during long flat bottom using Btrain (in BHN30) and show FFT of the signal → peak present at around 550Hz
2. Switch OFF possible sources of the tune ripple one-by-one and observe changes on the FFT signal:
   a. Test all families of normal quadrupoles → no effect
   b. Test the 2 families of skew quadrupoles → no effect
   c. Test the 2 families of sextupole pole face windings → switching off XFW01 makes peak disappear!

(see e-logbook entries from 26/04/2018)

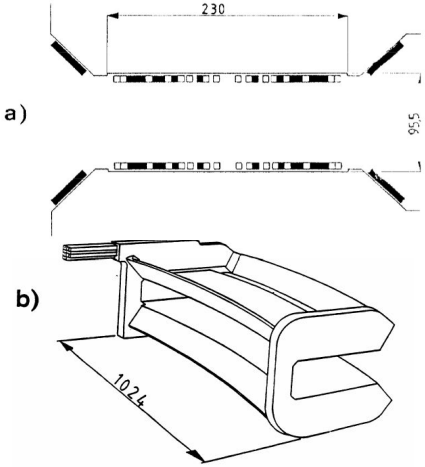


So what is exactly XFW01?

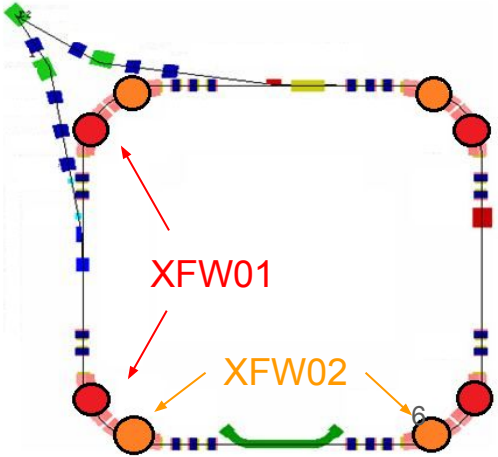
Sextupole windings are found on each end of the bending magnets. They are grouped in 2 families as shown.

They were used in LEAR as harmonic sextupoles to improve the dynamic aperture.

Optics in LEIR is different: Dx@XFW02 ~ 0 m, but Dx@XFW01 = -4 m. We do not use the sextupole windings in LEIR. However they should not just be put to 0, but power supply switched OFF. Otherwise tune ripple was observed.

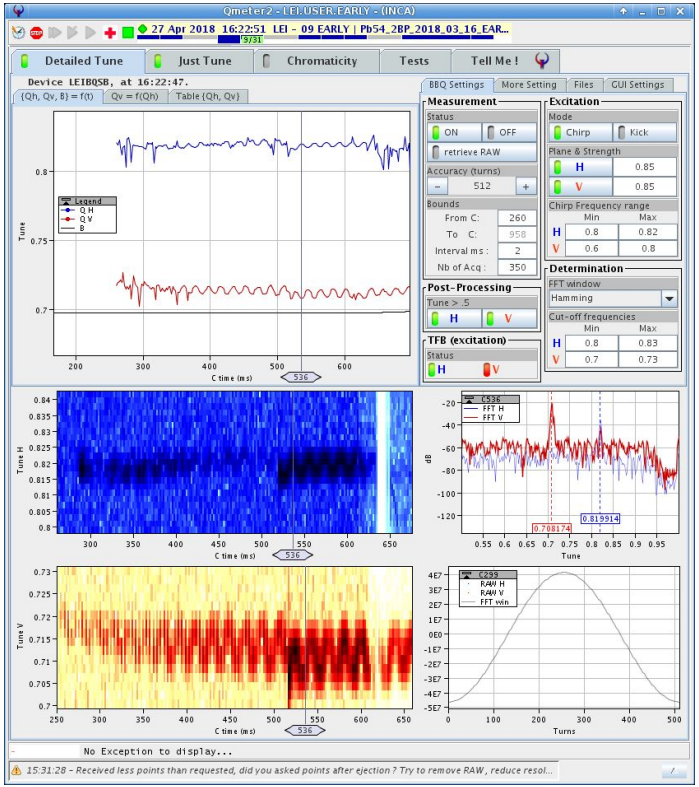


Sextupolar and dipolar pole face windings at LEAR
M. Chanel et al. CERN/PS 90-32

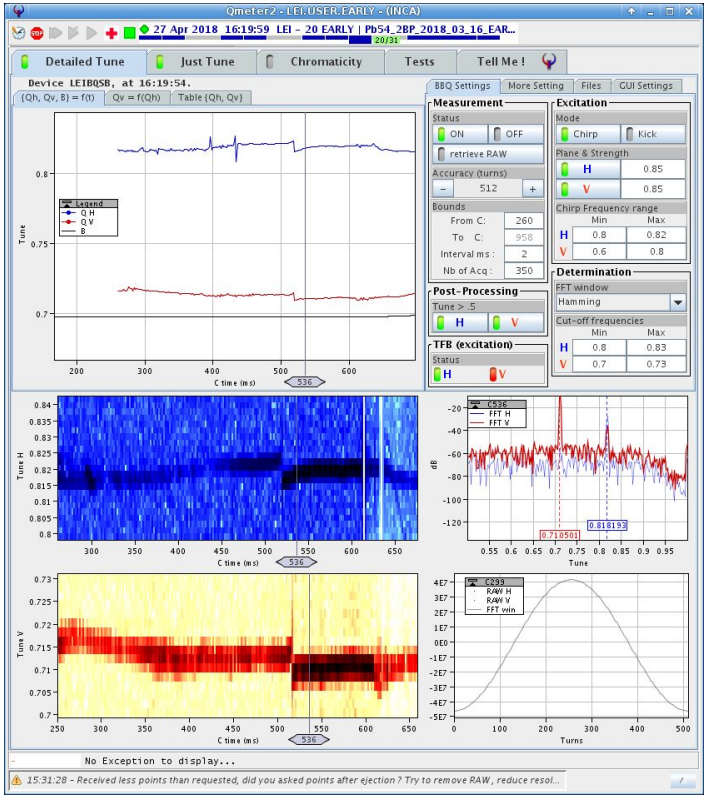


Switching OFF the XFW01

XFW01 ON



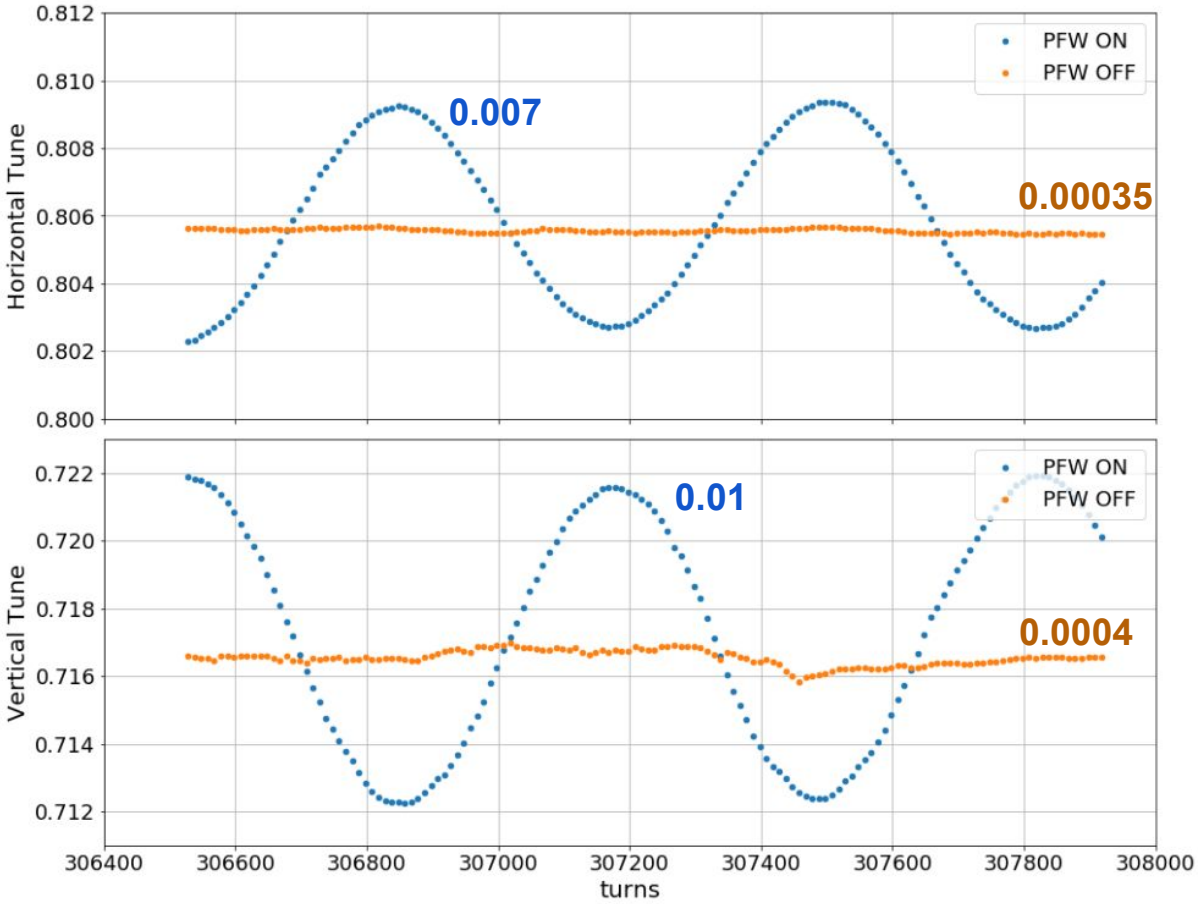
XFW01 OFF



Comparison of the effect on the beam

Horizontal tune ripple has opposite phase than the Vertical one!

K takes negative value when focusing and the opposite when defocusing

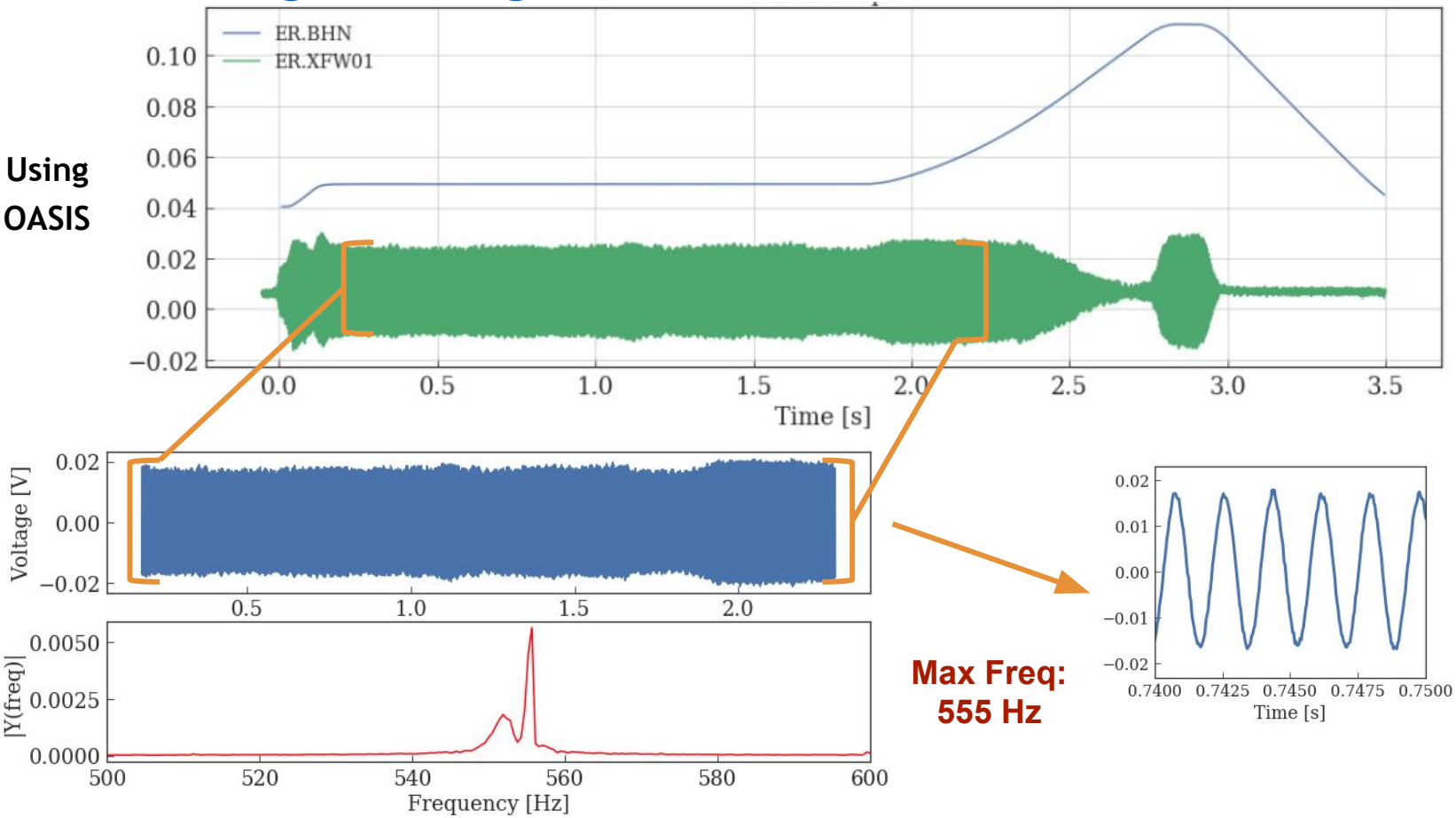


20 times smaller

25 times smaller

Measuring the signal from the hardware XFW01

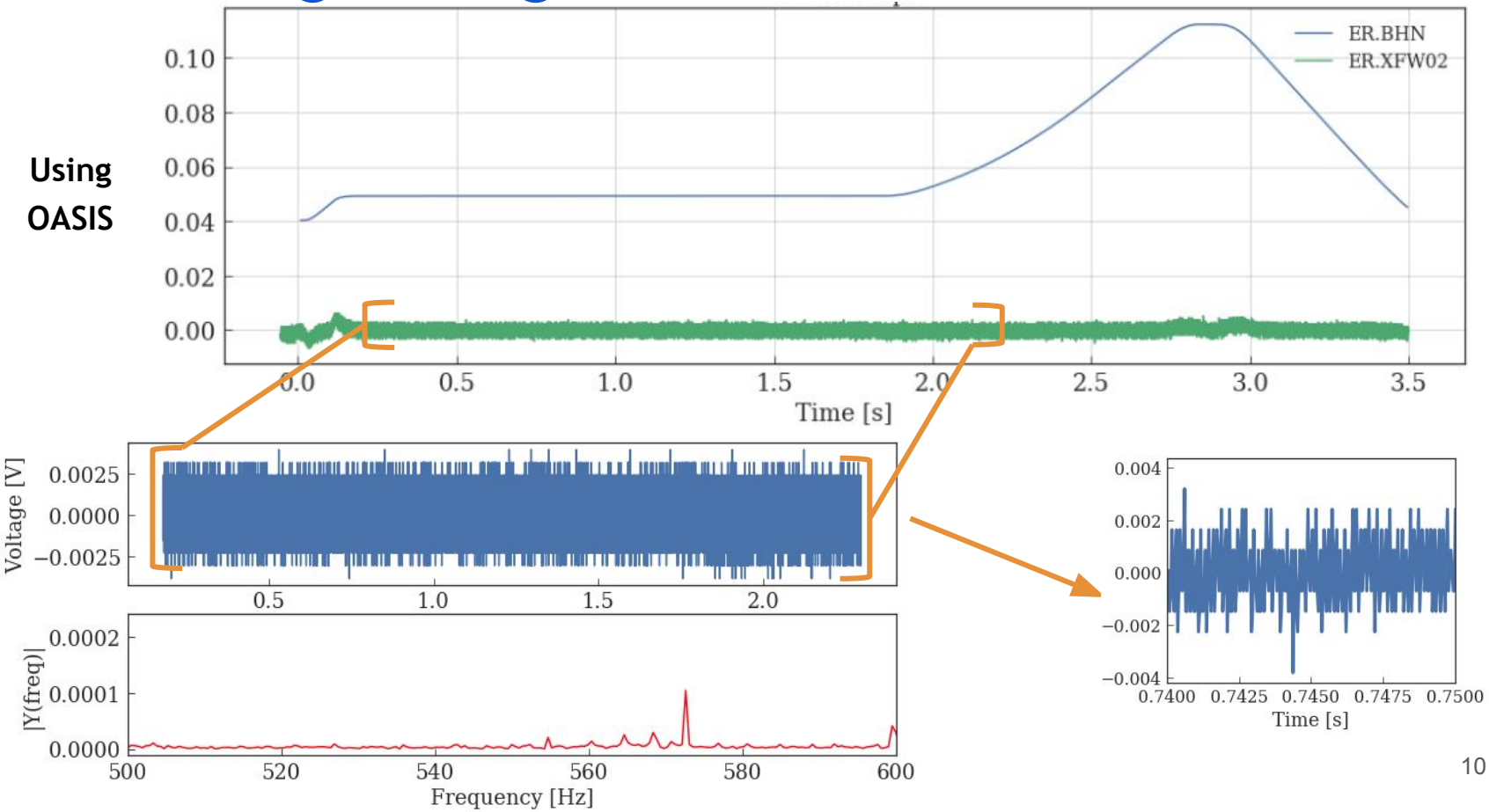
Using OASIS



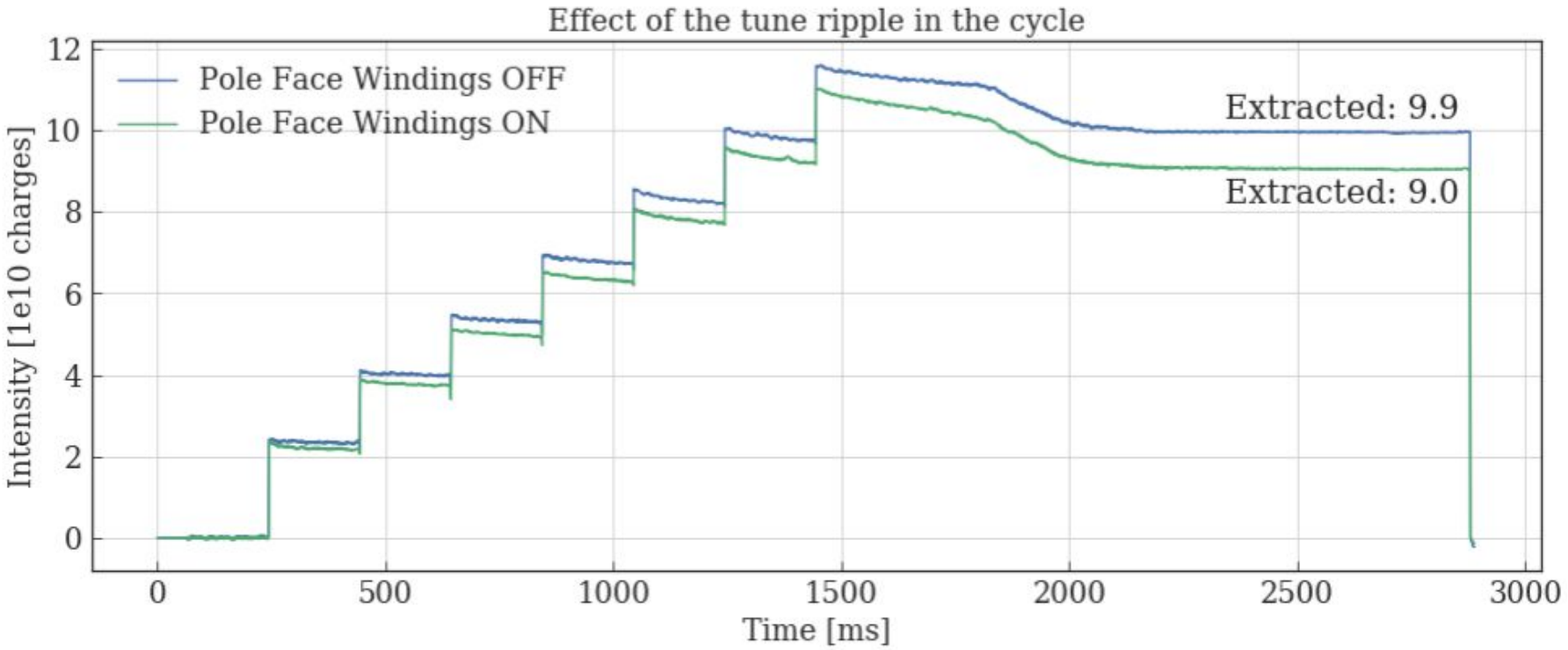
Max Freq: 555 Hz

Measuring the signal from the hardware XFW02

Using OASIS



Effect in the Extracted beam



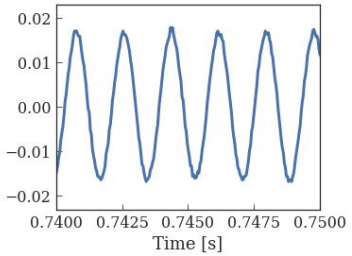
10% more beam!

Possible explanation: Feed down effect

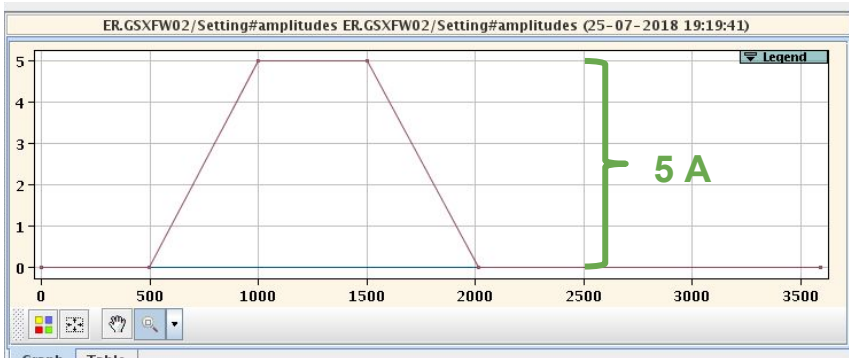
- How can the the XFW01 influence the Tune?
- **Possibility:** The coils create a sextupolar field that by feed-down effect produce a quadrupolar component that affects the Tune. Possible because now we have non-zero dispersion!
- The coils are set to zero, but the power supply gives energy to maintain that zero.
- **Proof:** Measure the magnetic field that it produces → Measure the Intensity circulating by the coil while they are ON (and set to zero).

Relation between Intensity and Voltage

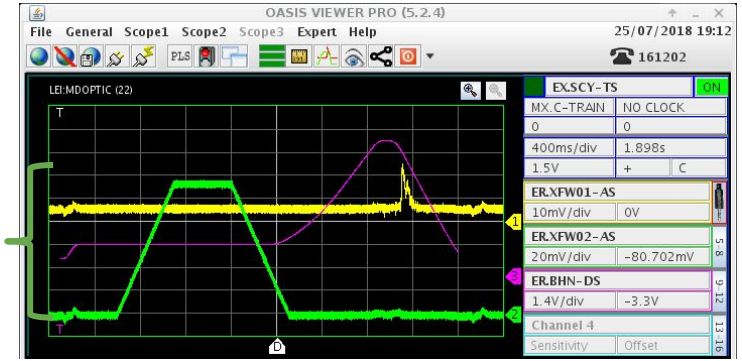
1. We measured the voltage with OASIS: 0.04 V peak-to-peak →



2. Set an Intensity in the XFW01, e.g. 5 A:



3. Measure again the voltage in OASIS:



5 A → 115 mV
x → 40 mV

I = 1.74 A

Feed-down effect

The PFW Magnetic Properties

The magnetic and electrical properties are shown in Table 1 while the magnetic field qualities are shown in Figs 2 and 3. The measurements were done by moving a hall probe along the magnetic radius of the bending magnet [4].

	Dipoles	Sextupoles
Nominal current ∫Bdl or ∫k'dl	150 A 130 Gm	150 A 5.4 Tm/m²
Resistance/coil	0.067 Ω	0.90 Ω
Voltage/coil	11.3 V	13.5 V
Water cooling	1.4 ℓ/min	1 ℓ/min
At pressure drop	8 atm	4 atm

Table 1 - Main Properties of the PFW's

Sextupolar and dipolar pole face windings at LEAR. (M. Chanel et al.)

$$\int Bdl = 5.4 \frac{Tm}{m^2} \frac{I}{150\,Amp}$$

$$S = 2 \frac{5.4}{\Delta L} \frac{I}{150} \left[\frac{T}{m^2} \right]$$

Sextupolar field

$$B = \frac{S}{2} x^2$$

From it extract the focusing strength: $k_2 = \frac{S}{B\rho}$

Calculate the focusing variation: $\delta k = k_2 D \frac{\delta P}{P}$

Calculate the tune ripple, including every element that produces a focusing variation:

$$\delta Q = \frac{1}{4\pi} \sum \delta k L \beta$$

Feed-down effect

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Dx@XFW01 ~ - 4 m
Dx@XFW02 ~ 0 m

Feed-down effect

One in each Bending

Around -4 m

1e-3

$$\Delta Q_x = 4 \frac{1}{4\pi} \frac{2 \cdot 5.4 \cdot I}{150 \Delta L} \frac{D}{B\rho} \frac{\Delta P}{P} L \beta_x$$

Brho = 0.97

BetaX = 9.71

BetaY = 10.76

Result:

$\Delta Q_x = 0.0015$

$\Delta Q_y = 0.0017$

October 2017

$\Delta Q_x = 0.0043$

$\Delta Q_y = 0.005$

December 2017

$\Delta Q_x = 0.007$

$\Delta Q_y = 0.01$

Probably depends on the orbit in addition to:

$$D \frac{\Delta P}{P}$$

But we cannot obtain the perfect explanation...

Feed-down effect

1. **Momentum difference** → that's why we also got different results in October and December
2. **Feed-down assumes perfect sextupolar field**, maybe these coils cannot produce a perfect one
3. Maybe the **specifications from LEAR** have changed, maybe the XFW are stronger

Idea to continue with the characterization:

- As now there's dispersion in the XFW01 position, we can use them as **chromatic sextupoles** and measure the **chromaticity** they create.

Conclusions

- Dangerous tune ripple has disappeared
- Probably produced by Feed-down effect
- Remind everyone to NOT turn ON the PFW
    - Not a PPM device! if switched ON for one cycle → will be ON for all cycles!

The END