Nonlinear optimization of the Ultra-low ($25\beta_x^* \times 0.25\beta_Y^*$) optics.

LCWS 2019, Sendai

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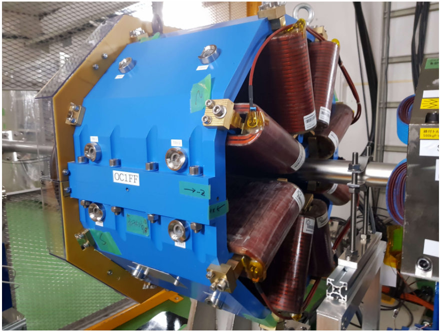
Outline

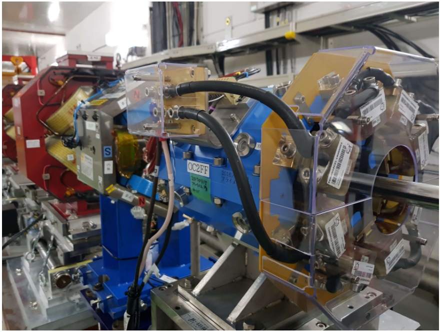
1. Octupoles setup optimization
   - Octupoles setup at ATF2
   - Swapped setup check
   - Tuning with octupoles
2. Linear and Nonlinear knobs for $25\beta_x^* \times 0.25\beta_Y^*$ optics.
   - Tuning knobs construction
   - Beam size tuning comparison
3. Summary

Octupoles goal at ATF2

- Ultra-low β_y^* optics for ATF2 is aimed to test the Final Focus System at chromaticity level similar to one at CLIC.



OCT1FF



OCT2FF

- Past studies on Ultra-low β_y^* tunability showed that higher β_x^* and a pair of Octupoles are needed: to compensate the **fringe fields** and the **higher order aberrations**.
- 2 Octupoles (**OCT1FF** and **OCT2FF**) were installed in **2017**.

Octupoles setup

- Strengths of the octupoles were optimized to be used with several Ultra-low lattices[1]:

	$1\beta_x^* \times 0.25\beta_Y^*$	$10\beta_x^* \times 0.25\beta_Y^*$	$25\beta_x^* \times 0.25\beta_Y^*$
OCT1FF k_3L [m^{-3}]	-36.6	-24.1	-90
OCT2FF k_3L [m^{-3}]	191.4	98	1770

- All the optics were tested in the simulations and at ATF2.
- The best tuning performance is expected for $25\beta_x^* \times 0.25\beta_Y^*$ (used as the main Ultra-low lattice).

According to the octupoles specification:

	k_3^L [m^{-3}], limit@50A
OCT1FF	730
OCT2FF	90

Limits the maximum yield, since k_3 of OCT2FF $>>$ limit.

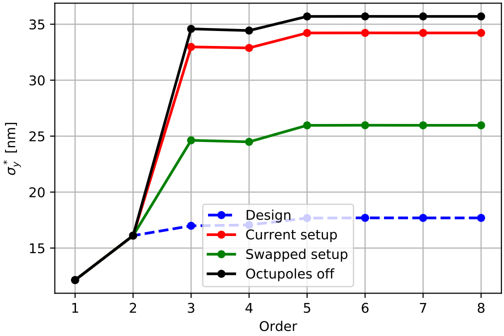
Although such a setup for $25\beta_x^* \times 0.25\beta_Y^*$ was expected to be very challenging to use, it was decided to keep it to examine for the possible corrections of the **multipolar errors**[2].

[1] F. Plassard, "Optics optimization of longer L^* Beam Delivery System designs for CLIC and tuning of the ATF2 final focus system at ultra-low β_y^* using octupoles".

[2] M. Patecki et al, "ATF2 tuning simulations versus observations for half β_y^* optics".

Swapped octupoles setup

- Design vertical beam size for $25\beta_x^* \times 0.25\beta_Y^*$ optics is **17.7 nm**. It requires a much stronger **OCT2FF**.
- Given the required octupoles strengths it was suggested to swap **OCT1FF** and **OCT2FF** and examine such a setup.



Vertical beam size for different setups:

Setup	σ_y^* [nm]
Design	17.7
Octupoles off	35.7
Current setup	34.2
Octupoles swapped	25.9
Octupoles swapped+ OCT1 off	26.6

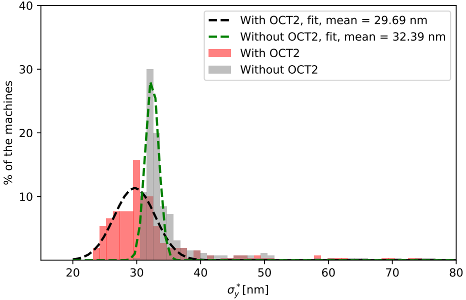
	k_3^L [m^{-3}], limit@50A	$25\beta_x^* \times 0.25\beta_Y^*$
OCT1FF	730	90
OCT2FF	90	1770

Swapped octupoles setup

While it is not possible to retrieve the design beam size, swapping octupoles can give the measurable beam size reduction.

- **Current setup:**
  The smallest beam size we can get is $\sim$ 34.2 nm, which is almost the same as without the octupoles. Practically, σ_y^* reduction cannot be seen with IPBSM.
- **Swapped setup:** The smallest beam size we can get is 25.9 nm (stronger magnet at 50 A and the weaker one at $\sim$ 33 A), which ideally gives a reduction of 10 nm.

Octupoles in the tuning process



Simulations setup:

- 260 machines simulated with randomly distributed static errors[3].
- Orbit and dispersion correction, sextupoles and OCT2 BBA, beam size tuning with linear/nonlinear knobs.
- Strength of **OCT2** is scanned based on the beam size with IPBSM@174 deg.

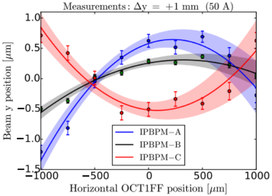
RMS value of the beam size reduction is **4.2 nm** with $\sim$ 30% of the machines reaching the beam size $<$ 30 nm.

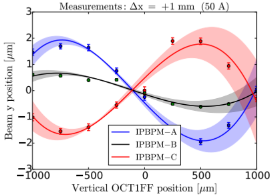
[3] T. Okugi et al, "Linear and second order optics corrections for the KEK Accelerator Test Facility final focus beam line".

Octupole alignment

Some comments regarding the octupoles alignment:

- From the past experience, we know that it is not possible to align the weaker octupole.
- Stronger octupole, currently, is at **OCT1** position and can be aligned with IPBPMs (practically, it is hard to perform).
- In June operation we also tried to align the **OCT1** by scanning the modulation.
- Putting the stronger octupoles at **OCT2** position allows us to use the downstream BPMs for the BBA.





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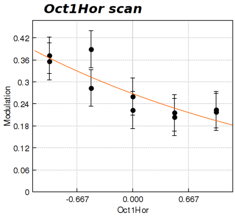
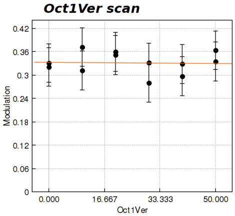




June 2019, Ultra low-β_y^* operation

Linear and Nonlinear knobs for $25\beta_x^* \times 0.25\beta_Y^*$ optics.

Tuning knobs construction

Tuning knobs are constructed in the way to correct each particular aberration independently.

- **Linear knob:**

$$R_{3i}^{knob} = \frac{< y, u^i >}{\sigma_y \sigma_{u^i}}$$

  Constructed **AX**, **AY**, **EX**, **EY**, **Coup$_2$**[4].

- **Nonlinear knob:**

$$T_{3ij}^{knob} = \frac{< y, u^i, u^j >}{\sigma_y \sigma_{u^i} \sigma_{u^j}} \equiv Y_{ij}$$

  Constructed $\mathbf{Y_{24}}$, $\mathbf{Y_{46}}$, $\mathbf{Y_{22}}$, $\mathbf{Y_{26}}$, $\mathbf{Y_{44}}$, $\mathbf{Y_{66}}$[5].

Calculations were done in Python with MadX and MAPCLASS.

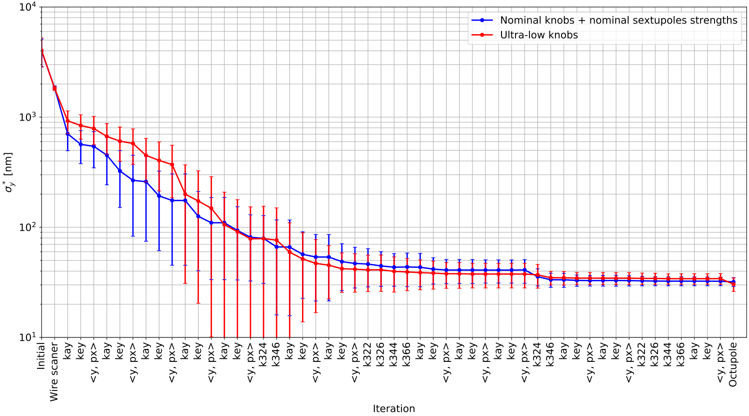
[4] **AX** - hor. waist shift, **AY** - vert. waist shift, **EX** - hor. dispersion, **EX** - vert. dispersion, **Coup$_2$** - $< y, x' >$ term.

[5] $\mathbf{Y_{24}}$ - $< y, y', x' >$ term, $\mathbf{Y_{46}}$ - $< y, y', \delta >$ term: normal sextupoles;
$\mathbf{Y_{22}}$ - $< y, x', x' >$ term, $\mathbf{Y_{26}}$ - $< y, x', \delta >$ term, $\mathbf{Y_{44}}$ - $< y, y', y' >$ term, $\mathbf{Y_{66}}$ - $< y, \delta, \delta >$ term: skew sextupoles

Beam size tuning comparison

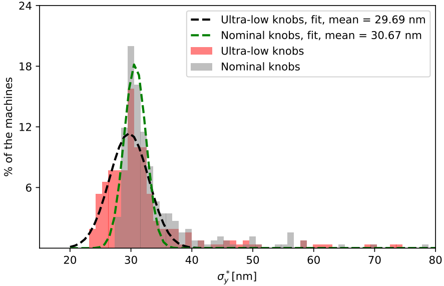
Comparing the beam size tuning with $25\beta_x^* \times 0.25\beta_Y^*$ knobs and $10\beta_x^* \times 1\beta_Y^*$ knobs.

- Tuning procedure comparison:



Beam size tuning comparison

Tuning knobs + octupoles:



- Nominal knobs (with nominal sextupole settings) and Ultra-low knobs have the similar performance with mean $\sigma_y^* \sim 30$ nm.

Summary and Conclusion

Summary

- Swapped octupoles setup provides the posibility to go below 30 nm vertical beam size, when the beam is well tuned with tuning knobs.
- 47% of the machines end up with $\sigma_y^* < 30$ nm.
- **OCT2** can be aligned with downstream BPMs, while **OCT1** should be switched off.

Outlook

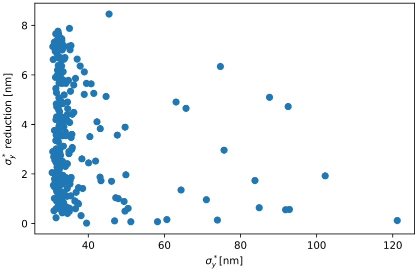
- It is expected to test the swapped octupole setup and the new tuning knobs in the next December Ultra-low β_y^* operation.

Thank you very much for your attention!

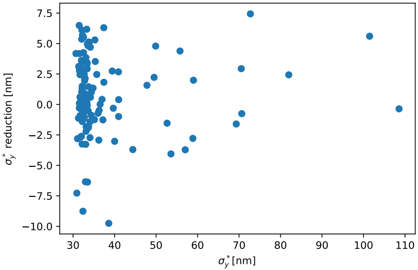
Back up slides

Beam size reduction

- **OCT1** is off



- **OCT1** is on



Beam size was scanned by means of strength iteration of **OCT2** for 2 setups, with **OCT1** on and off. It is clearly seen that **OCT1** should be off.

Tuning setup

Summary table of the errors considered in the tuning studies:[6]

Quadrupole, Sextupole	Alignment error	100 μm (Gaussian)
	Roll error	200 μrad (Gaussian)
	Strength error	0.1% (Gaussian)
BBA	Alignment accuracy	$\pm$ 100 μm (Uniform)
Wire scanner	Measurement error	$\pm$800 nm (Uniform)
IP-BSM	Measurement error, 2-8 degree mode	$\pm$100 μm (Uniform)
	Measurement error, 30 degree mode	$\pm$20 μm (Uniform)
	Measurement error, 174 degree mode	$\pm$8 μm (Uniform)
BPM	Measurement error	10 μm (Gaussian)

Tuning sequence:

- Ensure the beam reaches the IP.
- Orbit correction.
- Dispersion correction.
- Wire scanner, linear optics correction.
- Sextupoles are switched on, sextupoles BBA.
- Beam size measurement with IP-BSM and tuning with linear and nonlinear tuning knobs.
- **OCT2** alignment and strength scan.

[6] T. Okugi et al, "Linear and second order optics corrections for the KEK Accelerator Test Facility final focus beam line".

Tuning comparison

Analyzing 3 cases:

- Ultra-low knobs with ultra-low sextupole settings
- Nominal knobs with nominal sextupole settings
- Nominal knobs with ultra-low sextupole settings

Tuning comparison

- Minimum beam size: