Status of Crab Cavity Implementation in MADX and SixTrack

ColUSM #32

Javier Barranco García, Riccardo De Maria, Rogelio Tomas
CC Beam Dynamics

- The crab cavities (CC) are deflecting cavities operated with 90 degrees phase shift (crabbing). They are used to recover head-on collisions at the IPs.
- Two possible schemes: local (bump closed around a single IP) and global (single CC).
- The local one was used in KEK-B (lepton collider) when the luminosity world record was achieved.

Courtesy Y. Sun
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- Two possible schemes: local (bump closed around a single IP) and global (single CC).

- The local one was used in KEK-B (lepton collider) when the luminosity world record was achieved.

- The voltage needed in the CC will be defined by the crossing angle, energy, $\beta^{CC}$ and $\beta^*$, RF frequency.

- In order to keep the cavity surface fields below the upper limits commonly accepted SRF community (60 MV/m and 100 mT), the voltage per cavity is kept $\sim 3$ MV, i.e. 3 CC/IP/side. **Very recently the baseline is 4 CC/IP/side.**

- There are some studies on going by B. Dalena to decrease the total voltage (30-40%) by increasing the $\beta$ function at the Q4 and the CC (Q7+).
**CC Beam Dynamics**

The Hamiltonian of a CC reads,

\[ H_{crab} = \frac{qV}{P_0} \sin \left( \phi_s + \frac{\omega z}{c} \right) x \]

The transverse kick applied is **maximum for** \( z=|z_{\text{max}}| \) and zero at the center of the bunch. The convention used here implies \( z>0 \) for the head of the bunch and for \( V>0 \) then \( \Delta p_x<0 \) which is needed to ensure head on collision for a positive crossing angle.

\[ \Delta p_x = - \frac{\partial H_{crab}}{\partial x} = - \frac{qV}{P_0} \sin \left( \phi_s + \frac{\omega z}{c} \right) \]

In order to **preserve symplecticity** a kick in energy is needed.

\[ \Delta p_z = - \frac{\partial H_{crab}}{\partial z} = - \frac{qV}{P_0} \cos \left( \phi_s + \frac{\omega z}{c} \right) \frac{\omega}{c} x \]

Similar for a vertical CC, only changing \( x \) by \( y \).
CC in MADX

- CC element implemented in MADX for tracking purposes only in 2010. Twiss and other functionalities not yet committed to the repository. However if needed one can use the RF dipole with the proper phase as crab cavity, which is supported by Twiss and MADX tracking (although not extensively tested).

- An example from the MADX manual,

```
BEAM, PARTICLE=PROTON, ENERGY=7000.0;
CAVITY: CRABCAVITY, L=10.0, VOLT=5.0, LAG=0.0, FREQ=400,
       rv1=0, rv2=50, rv3=1000, rv4=50, rph1=100, rph2=500,lagf=0.125, TILT=0;
```

- TILT convention: a positive angle is a clockwise rotation. A $+\pi/2$ rotation means going from a negative horizontal kick to a negative vertical kick.

- Additional Tracking options: Voltage ramp (up to 4 turns), phase change (2 steps).

- Be aware of the units! VOLT [MV] and FREQ[MHz] ⇒ Same in SixTrack. But Phase LAG[2pi]⇒[rad] in SixTrack (this is NOT taken care by the MADX to SixTrack conversion yet). TILT[rad] translates into ± 23 hor/ver CC.

- MADX to SixTrack conversion produces one element ± 23 in fort.2 for each CC (see later SixTrack format).
Installing CCs in MADX

- The optics expert define the parameters and install the CCs in a particular lattice (typically HLLHC) in two steps.

- First: for a given optics the voltage is calculated by installing the CCs are installed first as TKICKER and the kick is matched to force $x=0$ for a $1\sigma_z$ particle at the IP (the MADX macros for this are in the slhc_sequence.madx file /toolkit/rematch_crabs.madx)

- Each of the optics in /afs/cern.ch/eng/lhc/optics/SLHCV3.1b have these kicks hard-coded (AHCRAB_L1B1, AHCRAB_R1B1, AHCRAB_L5B1, AHCRAB_R5B1,...)

- Second: the TKICKER are replaced by CCs with voltage calculated with the CC parameters and the kick previously matched.

- These scripts are not yet publicly released, they will put in the optics repository soon.

- From a practical point of view will be just enough for a given HLLHC lattice to call the CC installation and later “switch on” the cavities by setting for example, on_crab1 :=1.
CC in SixTrack

- CC were implemented back in 2006 so most likely will be available in your current executables.
- CC format in SixTrack:

  Crab Cavity
  
  Format: name type Voltage Frequency Phase
  
  Name: May contain up to sixteen characters
  
  Type: Type identifier is +23 and −23 for horizontal and vertical crab cavities respectively.
  
  Voltage: Crab Cavity voltage [MV].
  
  Frequency: Crab Cavity frequency [MHz].
  
  Phase: Phase of the excitation in radians

- Example of horizontal CCs in HLLHC fort.2 lattice,

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>acrabcca.15b1</td>
<td>23</td>
<td>3.819290017e+00</td>
<td>4.007896026e+02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0000000000e+00</td>
<td>0.0000000000e+00</td>
</tr>
<tr>
<td>acrabccc.r5b1</td>
<td>23</td>
<td>4.155008313e+00</td>
<td>4.007896026e+02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0000000000e+00</td>
<td>0.0000000000e+00</td>
</tr>
</tbody>
</table>
A new complete model of the CC will be released before Christmas together with several consistency checks (units, sign,...).

CRAB MADX $\rightarrow -V\sin(\omega z-\Phi)$

CRAB-RF Mult Six $\rightarrow -V\sin(\omega z+\Phi)$

RF Mult MADX $\rightarrow V\cos(\Phi-\omega z)$

There is as well a modified version of SixTrack for Machine Protection studies. This could be integrated into the new release but will be likely replace by a more flexible module where any parameter could be modified with a predefined pattern over time.
Conclusions and outlook

- A new release before Christmas is expected with a more friendly user CC environment MADX-SixTrack, plus additional features mentioned before.

- However the tools are ready to be used just watch units and sign conventions!

- We would like to get feedback regarding the type of simulations planned by the collimation/machine protection group to check whether additional changes in the code are needed.

- There is a HL-LHC WP 2.3 meeting scheduled for the 16th December tackling the new maps in SixTrack plus several consistency checks. Feel free to join. For more info you can contact directly Riccardo.