Beam Physics Note
TRI-BN-22-32
November 29, 2022

Transverse Centroid Tracking Through Axially Symmetric Accelerating Fields

Olivier Shelbaya, Rick Baartman

TRIUMF

Abstract: Tracking of the reference particle centroid through axially symmetric accelerating fields has been implemented in TRANSOPTR. The implementation and use are briefly discussed, and an example featuring the ISAC-DTL IH cavity fields is presented.

4004 Wesbrook Mall, Vancouver, B.C. Canada V6T 2A3 · Tel: 604 222-1047 · www.triumf.ca

Transverse Centroid Tracking

This note details the implementation of reference particle tracking in the envelope code TRANSOPTR[1, 2], for integration through time-varying accelerating fields[3]. In particular, for IH structures, the support stems induce a dipole electric field component on-axis, which causes transverse centroid displacement during field transit. As it was desired to better study and understand the magnitude of the dipole kicks in the ISAC-DTL, the source code was altered to enable this. However, as will be shown, much of the necessary framework was already in place, only requiring light modification to the source.

Centroids through the electric fields can now be tracked in TRANSOPTR by calling subroutine `linacn`[3]:

```
call linacn(100,164,1e-6*RFA1,32.6,1.0608e+08,1.0*RFP1,'DTL1')
```

The only difference is that the field distribution file (`fort.100`) can now optionally contain 4 columns of input data: $\{s,\mathcal{E}_z(s),\mathcal{E}_y(s),\mathcal{E}_x(s)\}$. If only two columns are supplied, they are assumed to be s,$\mathcal{E}_z(s)$, defaulting to the original behaviour. The user does not need to change any input parameter to `linacn`. Instead, a subroutine contained within the latter's source file automatically detects whether there are two or four columns of input data:

```
      SUBROUTINE TRY_FOUR(iunit,stat)
c     Olivier: Small subroutine that tries to read 4 elements from the first
c     line of the fort.stat input field map file. If it succeeds, variable stat
c     is set to zero. If it fails, it isn't zero. Paired w/ if statement after
c     calling TRY_FOUR, one can decide if we include dipole kicks or not to the
c     reference particle. If not, the dipole field values are just set to zero.
      integer :: stat
      READ(iunit,*)Z,EZ,DIPy,DIPx
      rewind(iunit)
      if((Z .EQ. 0) .and. (EZ .EQ. 0) .and. (DIPy .EQ. 0)
     &.and. (DIPx .EQ. 0))THEN
          stat=0
      endif
      end
```

With four input columns, the centroid through the field is tracked using the array `dsx` in the subroutine source file `LINAC.f`. This array contains the s-derivatives at each numerical integration step: Columns 1-12 contain beam and transfer matrix elements, while 13 holds (x,y) centroids in `dsx(13,1)` and `dsx(13,3)` and their divergences in `dsx(13,2)` and `dsx(13,4)`. Provided the dipole fields $\mathcal{E}_y(s)$ and $\mathcal{E}_x(s)$, the centroid at each step evolves as:

```
c     DIPOLE KICKS
      dsx(13,2)=DIPx*ccc/(BETA*Pold*100)
      dsx(13,1)=pratio*sx(13,2)
      dsx(13,4)=DIPy*ccc/(BETA*Pold*100) !1/100 converts from /m to /cm
      dsx(13,3)=pratio*sx(13,4)
```

The quantities `DIPx` and `DIPy` are the scaled values of the horizontal and vertical dipole fields, which have previously been read-in and interpolated using a cubic spline. **The fields must be normalized by the same scaling factor that is used to normalize the on-axis longitudinal electric field. This means all field inputs must be normalized with respect to the maximum value of $\mathcal{E}_z(s)$ in the dataset.** Finally, in the event that transverse fields are not supplied, the variables `DIPx` and `DIPy` are set to zero and cubic spline interpolation of their values is omitted.

The new centroid tracking capability has been used with the electric fields from the ISAC-DTL, shown in Figures 1 and 2. In each case, the cavity phase and voltage has been optimized for the maximum operational E/A for the reference particle, together with the condition $\mathbf{M}_{65} + \mathbf{M}_{43} + \mathbf{M}_{21} \longrightarrow 0$ [4]. Though the vertical centroid deviates most significantly from the beam axis for Tanks 4 and 5, the effect remains below 0.5 mm at the cavity exit. For a 10 m downstream field-free drift, this would cause a total centroid displacement of roughly 6 mm, which can easily be corrected using magnetic steerers in the HEBT line.

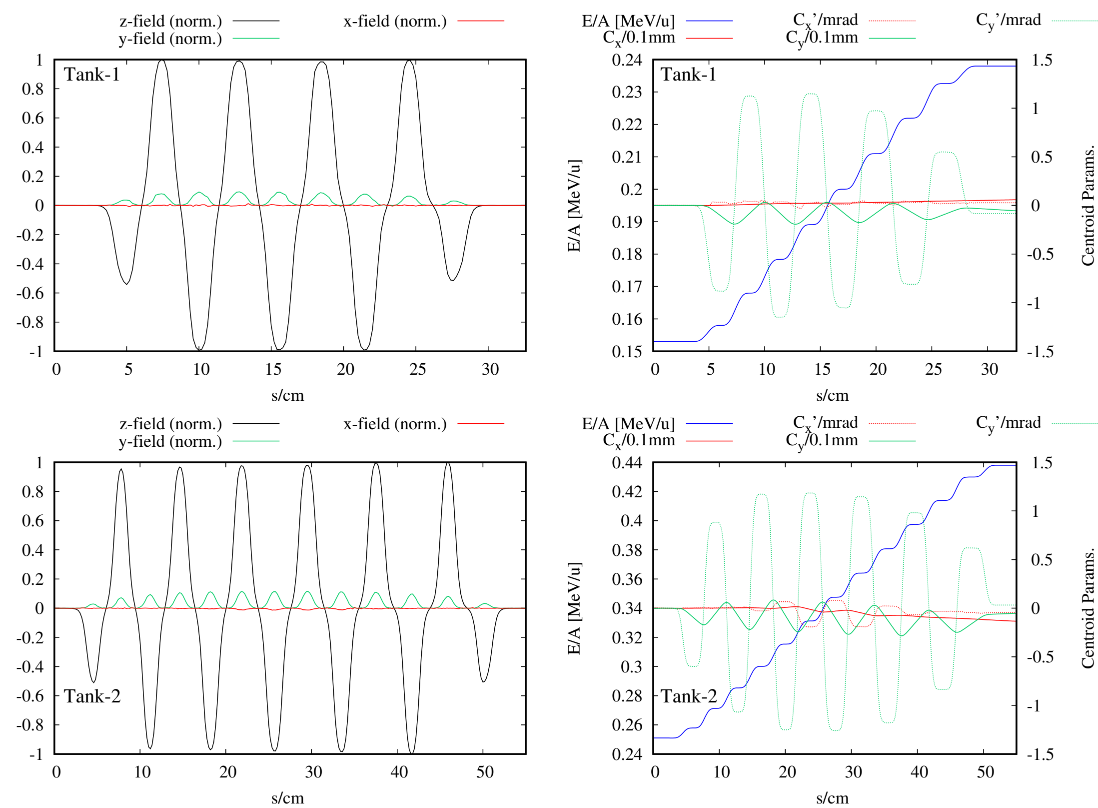

Figure 1: **Left:** On-axis intensity of the longitudinal (black), vertical (green) and horizontal (red) electric fields, normalized to the maximum longitudinal intensity in the dataset. **Right:** `TRANSOPTR` computed reference particle E/A is shown on the left hand y-axis, while the centroids (C_x, C_y) and their divergences are recorded on the left. Field simulation credit: Peter Braun, Holger Podlech, Klaus Kümpel et al. IAP-Goëthe Universität Frankfurt, 2022.

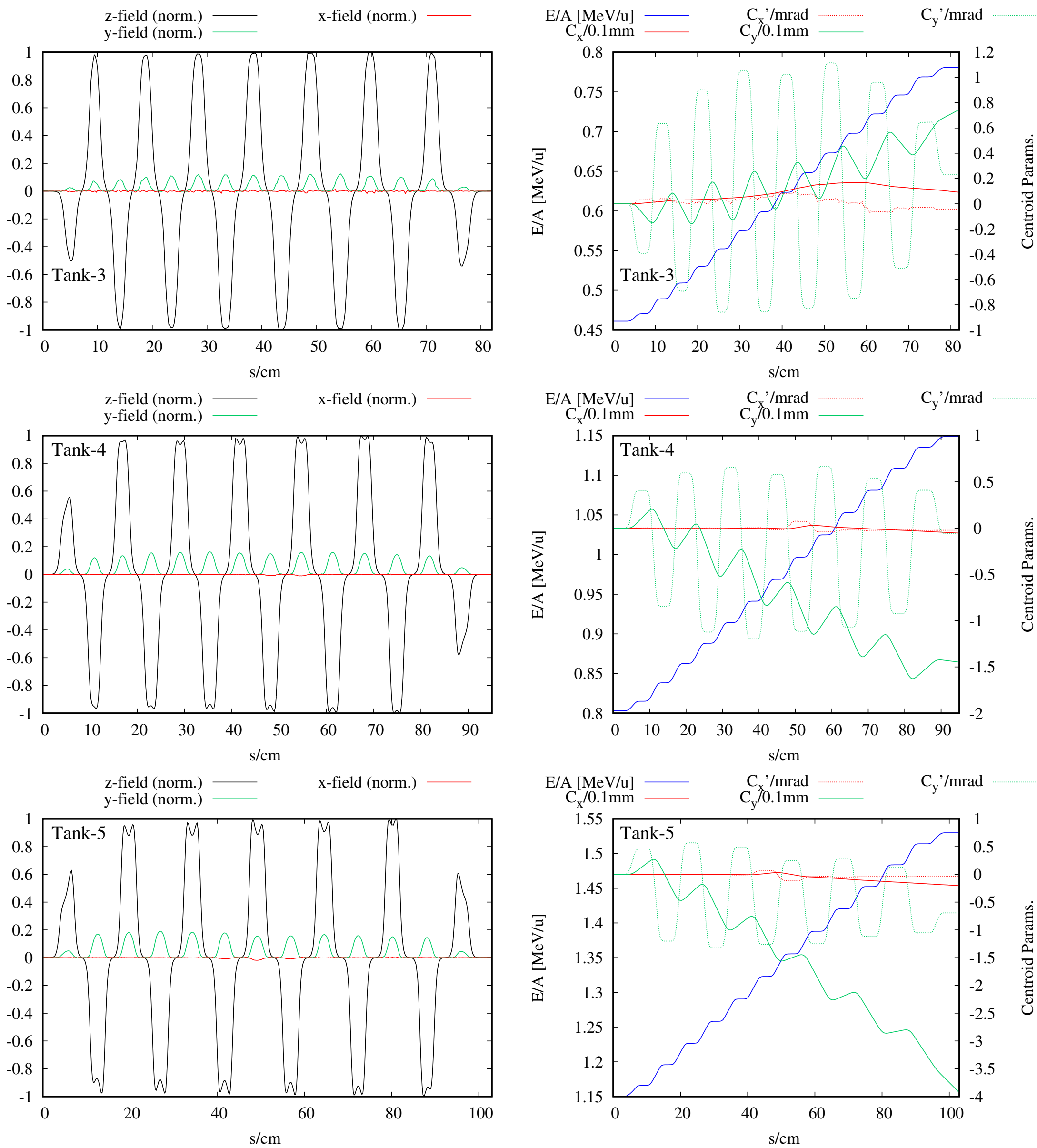

Figure 2: **Left:** On-axis intensity of the longitudinal (black), vertical (green) and horizontal (red) electric fields, normalized to the maximum longitudinal intensity in the dataset. **Right:** TRANSOPTR computed reference particle E/A is shown on the left hand y-axis, while the centroids (C_x, C_y) and their divergences are recorded on the left. Field simulation credit: Peter Braun, Holger Podlech, Klaus Kümpel et al. IAP-Goëthe Universität Frankfurt, 2022.

References

[1] Heighway EA and Hutcheon RM. *Transoptr - A second order beam transport design code with optimization and constraints*. Technical report, Atomic Energy of Canada Limited, 1981.

[2] Rick Baartman. TRANSOPTR Reference Manual . Technical Report TRI-BN-22-08, TRIUMF, 2022.

[3] Richard Baartman. Linac Envelope Optics. Technical Report TRI-BN-15-03, TRIUMF, 2015.

[4] Olivier Shelbaya, Tiffany Angus, Rick Baartman, Paul M Jung, Oliver Kester, Spencer Kiy, Thomas Planche, and Stephanie D Rädel. Autofocusing drift tube linac envelopes. *Physical Review Accelerators and Beams*, 24(12):124602, 2021.