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The TRANSOPTR Model of the ISAC Drift Tube Linear Accelerator - Part II: LORASR Comparison Notes

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Abstract: The multiparticle code LORASR is used to verify the transverse and longitudinal envelopes through the ISAC drift tube linac (DTL), in addition to verifying the phase dependent energy output of the machine. This document records notes of the comparison, such as conversion of longitudinal phase space units between codes.

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Conversion of LORASR and TRANSOPTR inputs

From parameter ESP (reference particle energy), compute initial relativistic parameters:

$$\gamma_i = \frac{\text{ESP}}{mc^2} + 1 \tag{1}$$

$$\beta_i = \sqrt{1 - \frac{1}{\gamma^2}} \tag{2}$$

$$P_i = \beta_i \gamma_i mc \tag{3}$$

. The parameter DMPH measures the distance from the reference particle to the maximum extent of the longitudinal distribution in phase space, along the momentum axis. HAPH measures the angular distance between reference particle and zero-momentum crossing of the distribution and HAE is the maximum extent of coordinate-6:

$$\texttt{HAPH} = \sqrt{\frac{\epsilon}{\beta}} \tag{4}$$

$$\texttt{DMPH} = \alpha\sqrt{\frac{\epsilon}{\gamma}} \tag{5}$$

$$\texttt{HAE} = \sqrt{\gamma\epsilon} \tag{6}$$

these to compute initial Courant-Snyder (CS) parameters[1]:

$$\epsilon = \texttt{HAE} \times \texttt{HAPH} \tag{7}$$

$$\alpha = \texttt{DMPH}/\texttt{HAPH} \tag{8}$$

$$\gamma = \texttt{HAE}/\texttt{HAPH} \tag{9}$$

$$\beta = \frac{1+\alpha}{\gamma} \tag{10}$$

Use these to compute the corresponding time and energy spreads of the bunch:

$$z = \beta_i c \frac{\Delta\phi}{360^\circ f} = 2\beta_i c \frac{\sqrt{\beta\epsilon}}{360^\circ f} \tag{11}$$

$$\tag{12}$$

In TRANSOPTR, the sixth coordinate is expressed as an angle, corresponding to the ratio of the longitudinal momentum is the Frenet-Serret frame, normalized to the total momentum of the reference particle:

$$z' = P_z/P_i = 2\texttt{HAE}/K = 2\texttt{A}\sqrt{\gamma\epsilon} \tag{13}$$

$$r_{56} = \frac{\alpha}{\sqrt{\beta\gamma}} \tag{14}$$

where A is the atomic number of the beam species, used since coordinate-6 in LORASR is expressed in keV/u. Note that these quantities are both given a factor of two, due to LORASR defining parameters HAE and HAPH as the half-axes of the distribution. With the following ellipse definition in LORASR's input file:

```
ELLI   1,1,1,1,1,1, PERC. CLUSTER PLOTS = 86
ENVELOPES : 1, PERC. = 86
```

[1] unsubscripted greek letters are assumed to be CS parameters.

Initial Alignment (Tank-1)

A ^{14}N^{3+} beam is used in both codes, with initial energy 2.121 MeV. The LORASR model of the ISAC-DTL includes a deck FIST which manually defines the IH cavity in terms of its drift tube structure:

```
FIST  DR.LENGTH   GAP LENGTH   DIAMETER
        4.299    1.260    1.40
        1.245    1.347    1.40
        1.254    1.415    1.40
        1.288    1.459    1.40
        1.347    1.460    1.40
        1.447    1.471    1.40
        1.544    1.422    1.40
        1.689    1.349    1.40
        1.803    1.347    1.40
       44.051
```

this is built directly from the values in [1]. Next, in the input LORASR file, under the GRUN deck, the first drift is set to 4.299 cm, which is equal to the distance from the Opera2D Tank-1 simulation starting point, until the tip of the first, external grounded drift tube (see [1], Tab. 2):

```
GRUN  GAP NO.= 9,SECTIONS= 1,STRUCTURE= 1,MASS= 14,CHARGE=3
      FREQUENCY= 106.08, PART.NO.= 5000, NDIST=2
      DRIFT= 4.299,GAP NO.= 9 ,NFREQ.=1,INJ. EN.= 2.121  ,PH.SHIFT= 0.0
      DRIFT= 44.051
```

This is the same as the first parameter in deck FIST. A previous TRANSOPTR simulation of DTL Tank-1, set for E/A = 0.237 MeV/u is used to find the effective voltages of each tube in the envelope simulation. This is done by setting TRANSOPTR to produce the desired output energy while minimizing $\mathcal{M}_{56}$, producing optimum energy gain without reference particle deceleration along the cavity. The effective voltages across each DTL gap are extracted from the optr simulation and are set in the LORASR input file deck VOLT:

```
VOLT 0.02298,1.000,1
     0.04414,1.000,1
     0.04945,1.000,1
     0.04822,1.000,1
     0.04939,1.000,1
     0.05244,1.000,1
     0.05263,1.000,1
     0.05132,1.000,1
     0.02647,1.000,1
      1.00000
```

The tube scaling factors are set to unity and the LORASR simulation is run, using distribution NDIST = 2 and 5000 particles. The starting distribution is defined as:

```
LRST  PULSE SHAPE AT INJECTION
      HALFAXES: HAE=  0.000924,   HAPH= 0.2272
                HAX=  0.669,  HATX= 9.58
                HAY=  0.644,  HATY= 9.617
      ELLIPSE ORIENT.: DMPH= 0.3634, DMX= -1.291, DMY= -1.3
      PULSE CENTER:    ESP= 2.121,  PHSP=  0.0
      MISALIGNMENT:  DXSP= 0, DTXSP= 0, DYSP= 0, DTYSP= 0
```

An initial drifting beam test is performed by turning off the cavity in both codes. In LORASR, effective voltages in the deck VOLT are set to 0.000000001. This strategy allowed for the establishment of the TRANSOPTR-LORASR verification recorded in [2].

References

[1] Olivier Shelbaya. The TRANSOPTR Model of the ISAC Drift Tube Linear Accelerator - Part I: Longitudinal Verification. Technical Report TRI-BN-20-08, TRIUMF, 2020.

[2] 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.

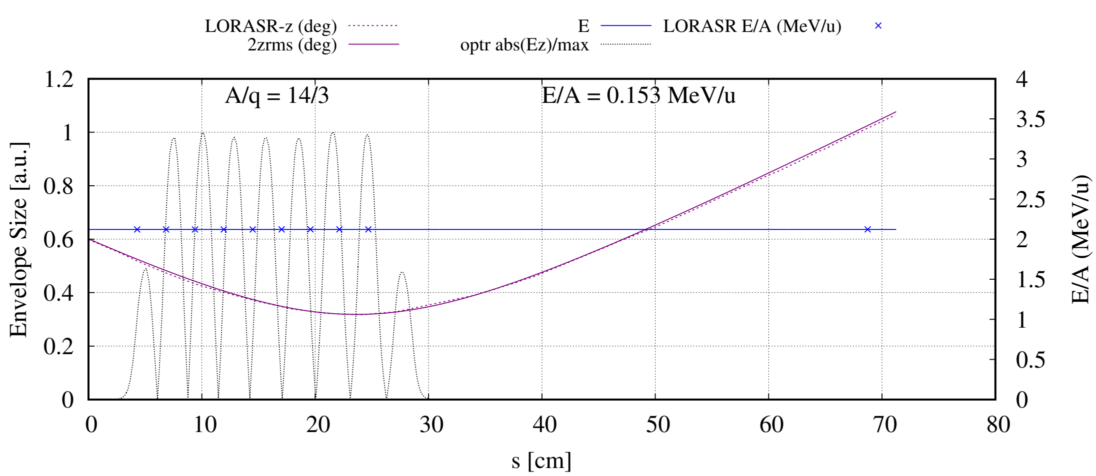

Figure 1: Comparison of TRANSOPTR (solid) and LORASR (dashed) 2rms envelopes. The absolute value of the longitudinal z-electric field in optr is shown as a dotted black line.