Y. Chao
October 20, 2013

Consequence of Ambient Fields in Various Parts of E Linac under Different Operating Modes

- Two values are chosen for ambient field levels spanning the range we are most interested in and most likely will work with
  - 0.2 G, representing the lower limit achievable given possibly elaborate active suppression and shielding
  - 0.5 G, representing the upper limit we are likely to tolerate, for which the beam at top energy is just stiff enough
- The results quoted below come from
  - Those presented over the past few years as design moved from 300 keV to 75 MeV, although not covering all operating scenarios
  - Re-interpretation of above, mainly in dissecting former blanket statements into finer pieces reflecting variation within a global unit (e.g., EHBT) or different operation scenarios (e.g., RLA vs ERL)
  - Newly obtained results filling gaps from above, mainly in
    - 0.5 G cases, which became a relaxed target from 0.2 G only recently for active suppression
    - Lower energy cases, including many cases where beam needs to be drifted through un-powered accelerating sections
    - Other previous untreated operation scenarios
- The much finer division of these effects, compared to previously presented, into sub-sections of E Linac constituent units, e.g., 4 sub-sections of EHBT, and into exhaustive enumeration of operating modes, e.g., multiple modes each for single-pass and two-pass EMBT-EABT-EHAT, reflects the often sensitive dependence of ambient field effect on beam property, optics, correction configuration and even hardware makeup of the line. In some former analysis a catch-all figure of merit was used for effects in terms of orbit offset or corrector strength. In this note such blanket statements are avoided as much as possible through these subdivisions by section and scenario, resulting in much more representative numbers for the section or scenario concerned as a whole.
- The purpose of the much finer subdivision is for a more sensible design of the active suppression scheme, such that any given area will not receive under or over-suppression due to insufficient granularity of the analysis, nor will any critical operation scenario be overlooked by the design.
- In the table below, each case consists of 4 figure of merits
  - 3σ stochastic orbit offset: This is the real 3σ corrected orbit envelop at all locations. It contains not only the ambient field effects (in terms of its RMS fluctuation), but also those from all other errors[1]. In many cases however the ambient field presents the dominant contribution[2].
  - 3σ stochastic corrector strength: This is the corrector strength required to combat the combined errors, including ambient field fluctuation of given RMS, up to 3σ envelope.
  - DC orbit offset: Change to the baseline orbit due to ambient field after correction. This is not the stochastic envelope, but the fixed orbit change due to a constant DC ambient field across the section of interest. This pertains only to ambient field.
  - DC corrector strength: Fixed corrector strength needed to correct the baseline orbit to the degree above. This pertains only to ambient field.

---

[1] An example is the 3σ stochastic corrected orbit in EHBT A (dogleg). Increasing ambient field level from 0.2 G to 1.0 G didn't change this number much, neither did it change the 3σ corrector strength, because they are dominated by injection error from upstream.

[2] An example is the EHAT drift case, where 3σ corrector strength needed didn't change from 7 MeV to 15 MeV under 0.5 G ambient field, since it is dominated by the latter.

- One possible interpretation is to superpose the stochastic envelope directly on top of the DC offset to get a worst case estimate for both the combined orbit and corrector strength.
- The “<” sign is an attempt to characterize the behavior of a less uniformly distributed collection of orbits or corrector strengths by singling out the outstanding peak(s). The need to do this further underscores the necessity to subdivide many sections as was done here.
- “Grain of Salt” with which to read these numbers –Underlying assumptions on the nature of errors may need to be considered when interpreting these numbers, which can lead to mitigating effects.
    - The method used to map probability in the analysis does not depend on the distributions being Gaussian. However, with a non-Gaussian distribution the meaning of 3σ (3 times RMS) becomes blurry. If one takes a flat distribution cut off at a finite value, then 100% of the distribution is contained within $\sqrt{3}$ of the RMS (σ), which is much tighter than Gaussian. The reality is somewhere in between and tends to modify these numbers downward.
    - There has been no consideration of error correlations. Actually many of the errors can be correlated, and not least the section-to-section ambient field. Whenever there is correlation the effect is <u>always</u> to reduce the worst case RMS because of reduced degrees of freedom and thus less “flexibility” to maximize errors within a <u>fixed</u> probability envelope. Analysis including such correlations can be done [1], but would require further quantification of such correlations. It may be practical at this point to just keep in mind that these numbers likely represent an overestimated level of <u>independent</u> errors.

  On the other hand there should not be singularity related effects in the orbit correction process as they are all taken care of. In cases where the above two factors are not relevant, the strict probabilistic interpretation of the numbers should hold. One should expect that the probability of a specific effect being <u>worse</u> than the 3σ value quoted will be <u>less</u> than 0.27%, and for 2σ, 4.55%, etc..
-

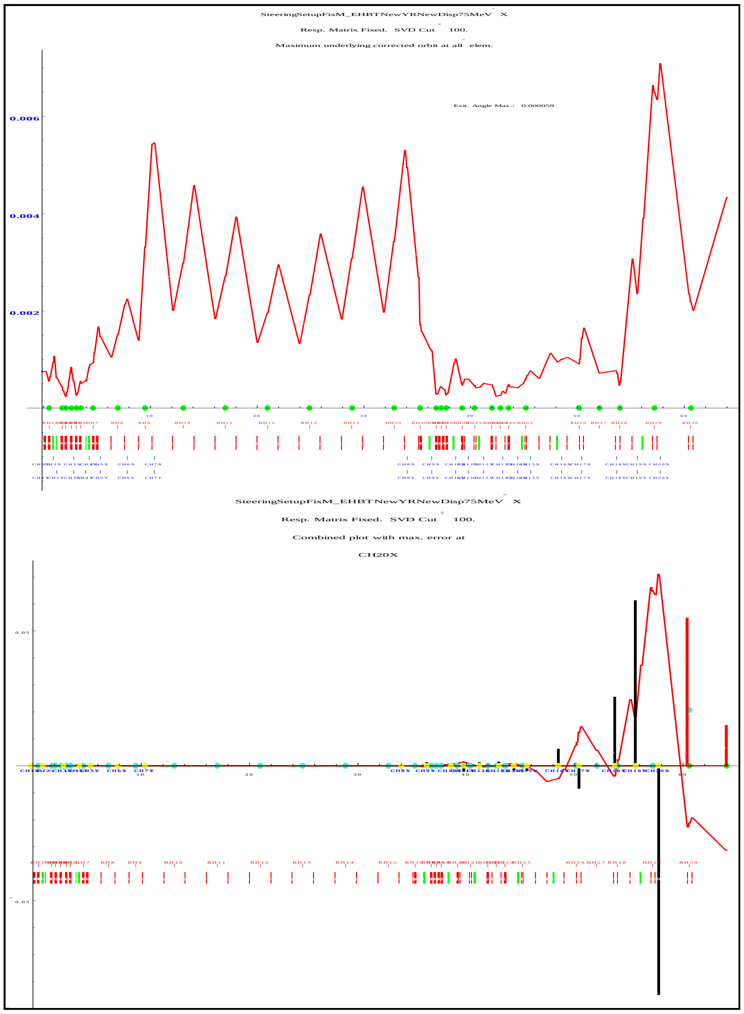
Consequence of Ambient Fields in Various Parts of E Linac under Different Operating Modes

		0.2 G for both DC offset and RMS fluctuation in ambient field					0.5 G for both DC offset and RMS fluctuation in ambient field				
Section/Mode	KE (MeV)	Orbit Offset (mm)		Corrector Strength (G-cm)		Explanation/Comment	Orbit Offset (mm)		Corrector Strength (G-cm)		Explanation/Comment
		3σ Stochastic	DC	3σ Stochastic	DC		3σ Stochastic	DC	3σ Stochastic	DC	
ELBT	0.3	0.3	0.1	18.7	6.3	Gun to ICM entrance	0.7	0.2	28.0	12.5	
EMBT 1P	7-15	<1.0	<0.1	<60	15	Single pass, full range of design energy	<1.0	<0.5	75	25	
EMBT ERL	7	2.5	0.2	<180	50	Part of combined multi-pass operation	2.5	0.9	180	120	
EMBT RLA	15-45	<1.0	0.1	<60	20	Part of combined multi-pass operation	<1.0	<0.2	90	65	
EABT Drift 1 ACM	7	0.7	0.2	120	55	Only first ACM installed and OFF	1.4	0.5	280	140	
EABT Drift 2 ACM	7	<1.0	0.2	40	24	Both ACM's installed and OFF	1.4	0.5	120	60	
EABT Drift 2 ACM	15	0.4	<0.1	50	24	Both ACM's installed and OFF	0.8	0.2	120	60	
EABT 1P	27-45	0.5	0.1	<140	50	One pass nominal, including 1 or 2 ACM ON	0.6	<0.5	300	120	
EABT ERL	27	<2.0	0.2	<60	35	Part of combined multi-pass operation	2.5	0.5	150	90	
EABT RLA	45-75	<0.5	0.1	<120	10	Part of combined multi-pass operation	<1.0	<0.2	300	100	
EHAT Drift 1 ACM	7	2.0	1.0	<140	60	Only first ACM installed and OFF	5.0	2.5	300	160	
EHAT Drift 2 ACM	7	2.0	1.0	100	60	Both ACM's installed and OFF	5.0	2.5	300	160	
EHAT Drift 2 ACM	15	<1.0	<0.5	110	60	Both ACM's installed and OFF	2.3	1.2	300	160	
EHAT 1 ACM	27-45	0.6	0.1	<140	60	One pass nominal, 1 ACM ON	0.5	0.2	300	150	
EHAT 2 ACM	47	0.5	0.2	<140	80	One pass nominal, 2 ACM ON	0.6	0.5	230	250	
EHAT ERL	47	<1.0	0.8	<90	50	Part of combined multi-pass operation	1.0	2.0	230	110	
EHAT RLA	45-75	<1.0	0.2	<180	55	Part of combined multi-pass operation	<1.0	0.5	300	140	
ERL Dump	7	1.5	0.4	65	25	Part of combined multi-pass operation	4.0	1.0	180	62	
EHBT A	45	<1.5	<0.2	<380	60	EHBT Dogleg section	<1.5	0.3	380	<150	
EHBT B	45	<4.0	<3.2	<420	<180	EHBT FODO section	<9.0	<8.0	<750	<400	
EHBT C	45	<1.0	<0.5	<150	<80	EHBT Switchyard	<2.0	<1.0	<250	<200	
EHBT D	45	<4.5	<2.2	<700	<250	EHBT Last dipole area	12.0	<6.0	1700	<700	
EHBT A	75	<1.5	0.1	<600	60	EHBT Dogleg section	<1.5	<0.2	<600	<150	
EHBT B	75	<2.5	<2.0	<660	<150	EHBT FODO section	<6.0	<5.0	<900	<400	
EHBT C	75	<1.0	<0.5	<220	<100	EHBT Switchyard	<2.0	<1.0	<260	<180	
EHBT D	75	<3.0	<1.5	<700	<300	EHBT Last dipole area	<7.0	<3.5	1700	<700	
EHDT	30	<2.0	1.0	<300	150	EHDT Entire line	4.2	2.6	600	320	
EHDT	75	<1.0	0.4	<400	150	EHDT Entire line	<2.0	1.0	680	330	

Facts / Observations / Remarks:

- Corrector specs recommended from previous analyses
  - Originally on 0.2 G ambient field: 28 G-cm for ELBT, 210 G-cm for EMBT (10 MeV) and 500 G-cm beyond, with a few exceeding 500 G-cm called out in EHBT.
  - Proposal in magnet PS spec sheet based on 0.5 G ambient field: 35 G-cm for ELBT, 700 G-cm beyond with option of 350 G-cm for EMBT, and few exceeding 700 G-cm in EHBT.
  - It is understood that RB Type B correctors (500 G-cm) will be used for EHBT in the current baseline. The numbers in the table can be used to predict performance through linear scaling.
- Naively discounting shielding and optics, and assuming 50 cm interval between correctors in ELBT, the orbit excursion caused by 0.2 G and 0.5 G ambient fields are about 1 mm and 3 mm respectively. This is a nontrivial difference at this energy given the beam size and its susceptibility. Shielding and optics theoretically improve this result, but we need more operational experience to really confirm this.
- 0.5 G ambient field can put ELBT correctors as spec'ed on the edge.
- EHBT Dogleg area has undergone configuration improvement [2]. The above table quotes the improved performance measures. A question was raised, as this section of EHBT seems quite robust against ambient fields, of whether it can take even more ambient field. This was actually already part of the original study [2]:

		1.0 G for both DC offset and RMS fluctuation in ambient field				
Section/Mode	**KE (MeV)**	**Orbit Offset (mm)**		**Corrector Strength (G-cm)**		**Explanation/Comment**
		3σ Stochastic	**DC**	**3σ Stochastic**	**DC**	
EHBT A	**45**	**<1.8**	**<0.6**	**400**	**300**	EHBT Dogleg section



- All multi-pass cases (ERL and RLA) have been analyzed before under two error scenarios [2]
  - Standard suite of errors (smaller) with 0.2 G ambient field.
  - Conservative suite of errors (larger) with 0.4 G ambient field

The first set of results were quoted in the above table, while the second set, not exactly matching the criteria for this note with its larger-magnitude error set, was not used. Instead cases corresponding to the standard set with 0.5 G ambient field were regenerated.

- The important question of ability to drift the ICM-accelerated beam through the entire EMBT-EABT-EHAT chain with or without the second ACM installed (either ACM not powered) has not been addressed before. This could be a situation showing vulnerability to the ambient fields. This was investigated [3] and the conclusion is that neither corrected orbit envelope nor corrector strength exceeded allowed tolerance.
- The inordinate numbers for the EHBT D section also require some explanation. A break-down of the error vector at 3σ corresponding to the worst case scenario revealed the situation shown on the right. The top plot is the envelope of the 3σ corrected orbit where the large peak is seen developing in this section. This is caused by the combination of errors depicted in the bottom plot,

which is dominated by ambient fields (red vertical lines) in this area. Firstly this is a relatively long drift without sufficient local correction, and secondly, there is an extra constraint that the trajectory angle at the end must be small enough to enter the dump. Thus instead of the usual situation where correctors only need to be as strong as the ambient field for point-to-point cancellation, here an effective orbit bump (red curve) needs be created where the obit is artificially cranked up first by upstream correctors (black vertical lines), to be turned over by another corrector twice as strong, and then eased into the dump, with both small X and X', by ambient field in the last step. This is a real scenario and in order to meet this special orbit correction requirement into the dump, we might want to consider an extra corrector near the entrance to the dump in addition.

References

[1]. Extension to orbit configuration analysis algorithm
http://trshare.triumf.ca/~chao/Extension%20to%20Orbit%20Correction%20Analysis.pdf

[2]. Previously reported results:

http://trshare.triumf.ca/~chao/Presentation_Review_Dec2010.pptx

http://trshare.triumf.ca/~chao/EMBT_EABT_EHAT_Config_AnalysisD.pdf

http://trshare.triumf.ca/~chao/EHBT_Performance.pdf

http://trshare.triumf.ca/~chao/EHDT_Performance.pdf

http://trshare.triumf.ca/~chao/DoglegSteeringWithAmbientField.pdf

[3]. New results:

http://trshare.triumf.ca/~chao/Drifting7MeV_EMBT_EHAT.pdf