JITTER TOLERANCE FOR CLARA

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Abstract

CLARA (Compact Linear Accelerator for Research and Applications) at Daresbury Laboratory will be a test-bed for novel FEL configurations. CLARA will consist of an RF photoinjector, S-band acceleration and transport to 250 MeV including X-band linearisation and magnetic bunch compression. Ensuring stability of the VUV radiation pulses is a key aim of the project. To this end, we investigate in detail the jitter tolerance of the machine. This will ultimately determine the pulse stability.

INTRODUCTION

CLARA is proposed to be the UKs national FEL test facility. Designed to be a flexible machine, capable of delivering a range of electron beams, CLARA will test and compare a variety of FEL schemes. Such electron beams include high peak current bunches for SASE operation, low-emittance velocity compressed bunches and long constant current bunches for seeding. For a full overview of the aims of the project, proposed layouts and details of FEL schemes under consideration see [1].

The seeded scheme poses challenges with respect to the beam dynamics and is largely dependent on the jitter of the electron beam with respect to the seed laser. Arrival time jitter is of special importance, as if this is larger than the width of the interaction region, no seeding will take place. To this end, a detailed jitter study has been carried out, a selection of results are presented.

OPTIMISED BUNCH

A seeded scheme requires constant bunch parameters over a large proportion of the bunch. An optimisation was performed and a distribution representative of the required bunch parameter was found. Fig. 1 shows the distribution in question, after tracking to the exit of linac 4. For further details on the compression and linearisation scheme the reader is referred to [2].

JITTER IMPLEMENTATION

We track the bunch from the photoinjector to the exit of linac 4. Tracking is carried out with ASTRA [3] to the exit of the first linac section to include space-charge, followed by ELEGANT [4] taking into account the effect of cavity wakefields, longitudinal space-charge and coherent synchrotron radiation emittance dilution. To obtain typical jitter values we undertake two studies. The first, a parameter scan study, in which a parameter associated with an element is scanned over a range of values, to determine the
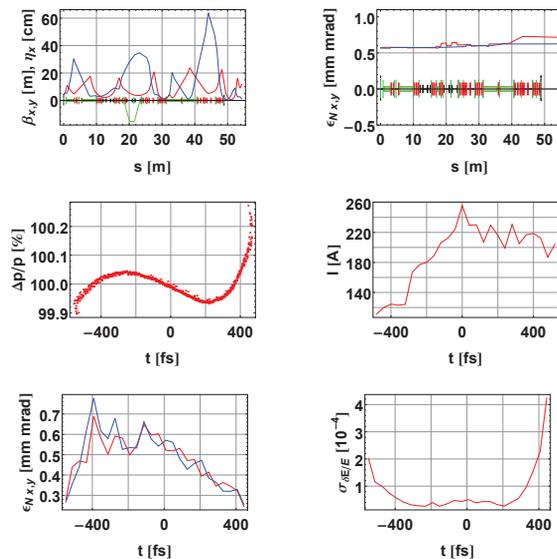
Figure 1: Norminal bunch (1) Optics: $\beta_{x,y}$ (Red, Blue) & η_x (Green). (2) $\varepsilon_{N(x,y)}$ less dispersive contributions (Red,Blue). (3) Longitudinal phase space. (4) Current profile (40 fs slices). (5) Normalised slice emittances (40 fs slices): horizontal / vertical (Red, Blue respectively) (6) Slice energy spread (40 fs slices).

parameters sensitivity. The second study involves imposing a random Gaussian error distribution over all parameters, over all elements. Running fifty such machines and then taking the RMS of all jitter values, we gain an expected jitter for a fully functioning machine. In both studies we impose errors on the intensity, timing and position of the cathode laser, the RF properties of all accelerating cavities and the dipole angles of the bunch compressor. When imposing errors on compression, all dipoles in the bunch compressor are subject to the same error, simulating a single power supply.

Consistent interface from ASTRA to ELEGANT

When carrying out jitter simulations in ASTRA one creates a single input file per parameter, varies the parameter accordingly, sets *High_res=.T* and executes the file. Note that the *ZSTOP* switch is the position at which the full distribution is written to the output file, if jitter is to be accessed at a point before *ZSTOP*, then *ZSTOP* should be set to this position. The *SCREEN* switch is not sufficient for this purpose. The output file is then transformed to sdds format, using the program *astra2elegant* [4], *sddscombine* is then used to combine all output files to a single file, with the nominal distri-

Table 1: Tolerance and jitter data for the long pulse mode. Each parameter listed is varied over the range stated, change in arrival time, RMS energy spread, RMS bunch length and mean energy at the exit of linac 4 are tabulated.

Parameter Varied	Range	Δt_{arr} (fs)	$\Delta \delta E$ (%)	$\Delta \sigma_{z\,RMS}$ (%)	ΔE (%)
PI Laser Δx	± 0.1 mm	1.1	1	0.06	0.0004
PI Laser Δy	± 0.1 mm	0.6	0.27	0.08	0.0004
PI Laser Δt	± 300 fs	3	1.8	1.9	0.05
PI Laser $\Delta \sigma$	± 10 %	15	50	9	0.06
Bunch Charge	$100 - 300$ pC	60	200	25	0.16
Gun ΔV	± 1 %	110	4	4.5	0.06
Gun $\Delta \phi$	$\pm 1\,^o$	90	3.5	3.5	0.1
Linac 1 ΔV	± 1 %	400	2.6	2.5	0.35
Linac 1 $\Delta \phi$	$\pm 1\,^o$	250	9	7	0.2
Linac 2 ΔV	± 1 %	50	3	3	0.5
Linac 2 $\Delta \phi$	$\pm 1\,^o$	550	16	15	0.6
Linac X ΔV	± 1 %	55	1	0.9	0.05
Linac X $\Delta \phi$	$\pm 1\,^o$	20	3	3	0.02
Linac 3 ΔV	± 1 %	2.5	0.45	0.007	0.4
Linac 3 $\Delta \phi$	$\pm 1\,^o$	3	0.5	0.0035	0.3
Linac 4 ΔV	± 1 %	0.9	0.4	0.0015	0.4
Linac 4 $\Delta \phi$	$\pm 1\,^o$	0.7	0.36	0.0025	0.3
BC ΔB	± 0.01 %	10.5	7	6	0.5

bution as the first page of the resulting file. When using ELEGANT for jitter simulations, a single input file is created using the namelists *&LOAD_PARAMETERS* and *&SDDS_BEAM*. *&LOAD_PARAMETERS* points to a user defined sdds file, which contains an error configuration per run per page. *&SDDS_BEAM* points to the single sdds file containing all distributions, the switches *prebunch=1* and *reuse_bunch=0* should be set accordingly. The switch *first_is_fiducial* in the namelist *&RUN_CONTROL* is also set true. Now when executed the input file will load each page of said sdds files for *n_steps*. Using such a method results multiple paged output files with the page number corresponding to the run number. The above method is an adoption of the work done on the UK New Light Source Project [5].

PARAMETER SCANS

Scans were completed over all parameters for four variables, namely arrival time of the mean electron, RMS energy spread, mean energy and RMS bunch length. We accessed each variable at six points along the machine, specifically after every accelerating cavity and on the exit of the bunch compressor. Fig. 2 shows four such scans. First order linear dependencies are the trend for all but scans involving the horizontal and vertical offsets on the cathode, which show a quadratic dependence. This is expected as the photoinjector is axially symmetric.

Combining plots along the machine we can track the evolution of each variable, Fig. 3 shows such a plot. Reading off from each scan we can predict the change in all variables for all parameters, Table. 1 shows such figures at the exit of linac 4. The phase of linac 2 is shown to have the
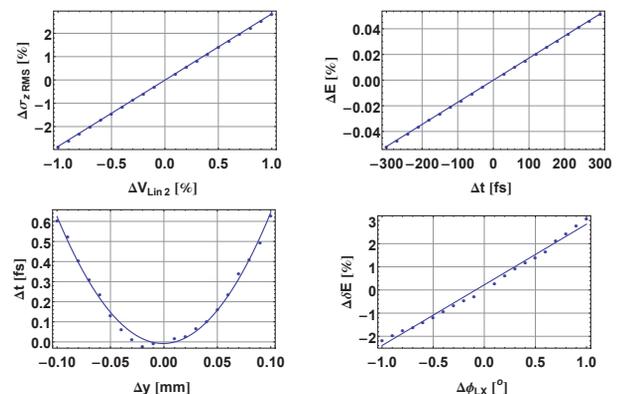

Figure 2: (1) Change in RMS bunch length at the exit of linac 4, while varying the voltage of linac 2 (2) Change in Mean Energy at the exit of linac 4, while varying the photoinjector lasers arrival time on the cathode, where the mean energy is 217.820 MeV. (3) Arrival time of the mean electron at the exit of linac 4, while varying the horizontal offset of the cathode laser, (4) Change in Energy spread at the exit of linac 4, while varying the phase of the 4th harmonic cavity.

greatest sensitivity over all variables. It is indeed the case that all parameters on all elements before compression have the greatest effect on the resulting distribution.

RANDOM GAUSSIAN DISTRIBUTED ERRORS

Fifty simulation set with random Gaussian distributed errors on all parameter, with RMS given in Table 2, were
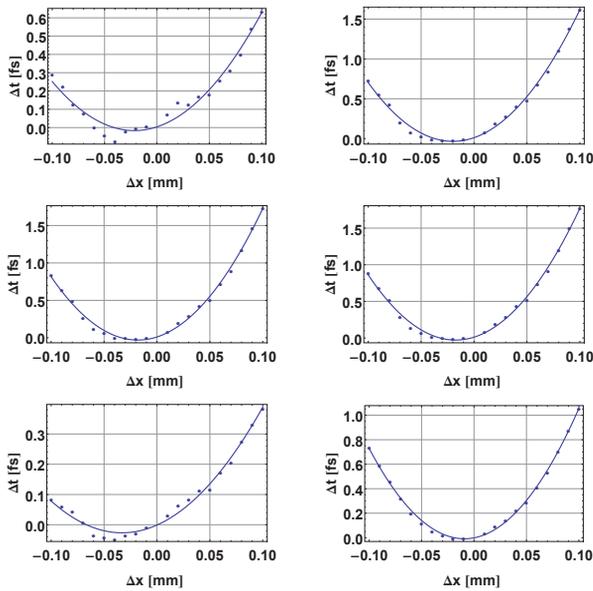
Figure 3: Change in arrival time of the mean electron at various point along the machine, while varying horizontal offset of the cathode laser; (1)Exit of gun, (2) Exit of linac 1, (3) Exit of linac 2, (4) Exit of 4th harmonic cavity, (5) Exit of the bunch compressor, (6) Exit of linac 4.

executed. By statistically analysing all fifty changes, we produce a RMS, which can be interpreted as the expected jitter value for a fully functioning machine. Plots showing each variable over the fifty machines were created, Fig. 4 & 5 show examples of such plots. The RMS values gained from such analysis are given in Table 3. The expected arrival time jitter is significantly smaller than the ~ 300 fs interaction region, therefore stability of the VUV radiation pluses can be achieved.

Table 2: RMSs of the Gaussian distributions used to simulate fifty machines.

RMS	Value	RMS	Value
$\sigma_{\Delta\sigma\,laser}$	5%	$\sigma_{\phi G}$	0.1°
$\sigma_{\Delta x\,laser}$	10%	$\sigma_{V(L1,L2,LX,L3,L4)}$	0.1%
$\sigma_{\Delta y\,laser}$	10 %	$\sigma_{\phi(L1,L2,L3,L4)}$	0.1°
$\sigma_{\Delta t\,laser}$	200 fs	$\sigma_{\phi LX}$	0.3°
$\sigma_{Q\,bunch}$	2%	$\sigma_{BC\Delta B}$	0.001%
σ_{VG}	0.1%		

Table 3: The RMS bunch properties for the fifty jittered machines with respect to the nominal machine.

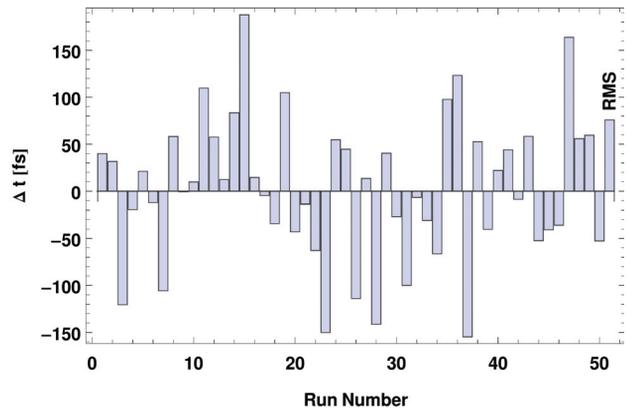| Variable	RMS
Δt_{arr} (fs)	63.95
$\Delta \delta E$ (%)	18.56
$\Delta \sigma_{z\,RMS}$ (%)	4.98
ΔE (%)	0.10

Figure 4: Change in arrival time of the mean particle for fifty machines with Gaussian distributed errors over all component, with RMSs specified in the Table 2
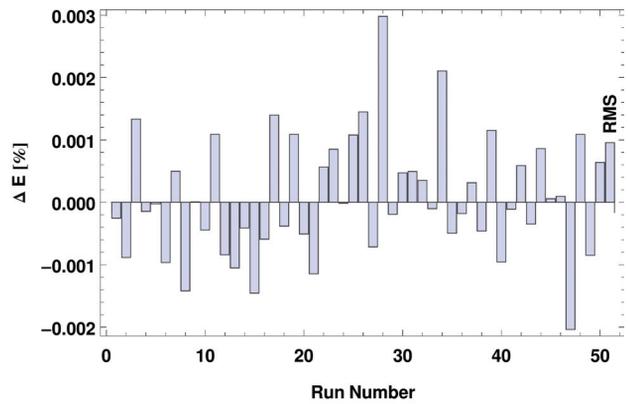

Figure 5: Change in Mean energy for fifty machines with Gaussian distributed errors over all component, with RMSs specified in the Table 2

CONCLUSION

As expected, elements prior to the bunch compressor contribute the dominant source of jitter. This will be used to inform component specifications and environmental conditions in the accelerator area. This analysis will be used to refine the machines working points as the project develops.

REFERENCES

[1] J. A. Clarke et. al., TUPEA058, these proceedings.

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[3] K. Flöttmann, http://www.desy.de/~mpyflo.

[4] M. Borland, Advanced Photon Source, LS-287 (2000).

[5] NLS Project: Conceptual design report, Jon Marangos et. al., 2010.