ESS LINAC
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Subject :

Sensitivity of the ESS linacs to RF field errors

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Sensitivity of the bunch rotation line

The injection of the short pulse in the storage ring requires a small jitter in beam phase and energy out of the Linac.
To reduce the energy spread of the beam injected into the storage ring, a beam phase extension line (about 70 m drift length) coupled with a buncher cavity is used. This system also has the property to recover the energy of the beam that is required by the ring under the assumption that the energy is not correct at linac output (within certain limits). However, a beam phase error at linac exit induces an energy error after the bunching cavity.

- Preceding work (presented at the 2002 January TAC meeting) on the beam energy compression line associated with the ESS superconducting linac has shown a sensitivity of the beam energy after the buncher of:
  - -175 keV per 1 MeV energy offset at linac output,
  - 190 keV per 1° phase offset at linac output.

Because the tolerance for the ring injection is ± 700 keV [1],offsets in phase $d\varphi$ (in °) and energy dE (in MeV) must satisfy:

$$\left| d\varphi \cdot 190 - dE \cdot 175 \right| < 700 .$$

- Concerning the normal-conducting option, ref. [1] gives the formula for the voltage of the energy compensation cavity:

$$V = \beta^3 \gamma^3 \cdot \left(mc^2 / e \right) \cdot \frac{c}{2\pi f \cdot l} ,$$

with V = 12.4 MV for f = 560MHz and l = 70m.

This result gives a sensitivity of:

- 216 keV per 1° phase offset at linac output.

The sensitivity to beam output energy depends on beam dynamics of the achromatic line. However, this effect will be probably small compared to the phase offset sensitivity. For example, using the same values for the sc-linac:

- -175 keV per 1 MeV energy offset at linac output,

one should then have:

$$\left| d\varphi \cdot 216 - dE \cdot 175 \right| < 700 .$$

Errors on field phase and amplitude

In order to quantify the sensitivity of the superconducting linac to cavity field errors, a random error with a homogenous distribution of ±0.5%, ±0.5° has been used in the calculations. This is equivalent to an rms error of 0.25% and 0.25°, or to a ±0.647%, ±0.647° gaussian error truncated at 2.5 rms.

ESS SC 704MHz option

3 different codes, written independently, have been used to calculate the effect of the random errors on the beam final energy and phase distributions. These distributions are gaussian (as

can be demonstrated from statistical calculations). Their average value is the energy and phase without error, and their standard deviations found by each code have been shown in the following table.

	Alban’s code	TraceWIN	PARTRAN
Energy (keV)	400 (±2%)	408 (±6%)	415 (±20%)
Phase (°)	0.6 (±2%)	0.56 (±6%)	0.55 (±20%)

The given uncertainties correspond to $\pm 2/\sqrt{N}$, N being the number of generated linacs.

Taken the more precise case (0.6° and 400 keV), one finds an energy offset standard deviation of 134 keV after the energy error compensation cavity. For 4 standard deviations (number of excluded cases: 6.34 10^{-5}) in 700 keV (tolerance), one can tolerate an error on linac cavities field phase and amplitude of 0.65° and 0.65% respectively.

ESS NC 560MHz option

A 560 MHz CCL has been designed from 100MeV to 1334 MeV. The first 60 cavities have 8 cells each and increase the beam energy to 250 MeV. The following 228 cavities have 10 cells each and increase the beam energy up to 1338 GeV. The linac was truncated (the first 36 cavities were suppressed at linac input) in order to begin at 188 MeV for a fair comparison with the superconducting one (beginning at 185 MeV).

Three cases have been studied:

- 1 cavity per klystron,
- 2 cavities per klystron,
- 4 cavities per klystron (close to the ESS nc option).

Standard deviations for beam energy and phase distributions at the linac exit for each case (using TraceWIN[1]) are shown in following table.

	1 cav./klys.	2 cav./klys.	4 cav./klys.
Energy (keV)	274 (±10%)	364 (±10%)	487 (±10%)
Phase (°)	0.59 (±10%)	0.88 (±10%)	1.17 (±10%)

One observes that the standard deviation scales as the inverse of the square root of the number of sources.

Taking the case of 4 cavities per klystron (the closest one to nc RAL option where there are 4 or 6 cavities per RF supply), 1.17° and 487 keV, the energy offset is 267 keV after the energy error compensation cavity. For 4 standard deviations in 700 keV (tolerance), one can tolerate only an error on cavity field phase and amplitude of 0.325° and 0.325% respectively, two times more stringent than that for the superconducting linac.

[1] TraceWIN has been compared and validated with the code used by Ken Crandall at Los Alamos for SNS on a test-linac (220 10-cells cavities, E0T=2.7MV/m, phis=-25°, 1βλ between cavities, input energy: 185MeV, output energy: 1324MeV, 5 cavities per klystron, +/- 0.5°/0.5% peak-to-peak (uniformly distributed) errors in klystron field). In this test, Ken ran 10,000 linacs and found gaussian output beam phase and energy distributions with standard deviations: 1.24° and 0.64MeV. With TraceWIN, we ran 100,000 linacs and found gaussian output beam phase and energy distributions with standard deviations: 1.25° and 0.62MeV. The codes are very different and using different models to simulate the cavities. They however exhibit a very good agreement.

Conclusion

The ESS 560MHz nc option is 2 times more sensitive to field errors than the ESS 704MHz sc linac. The shorter sc-linac, the higher number of RF sources of sc-linac and the stronger longitudinal focusing of sc-linac are main reasons of this.

References

[1]"ESS Accelerator Team", *The ESS Accelerator and Beam Lines with the 280/560 MHz Linac*, TAC Meeting n°1, FZ Juelich, 07-09 January, 2002.