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HIGH POWER BEAM AT SLAC*

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Abstract

The fixed target experiment E-158 has been running with an electron beam close to the highest possible charge and energy available at the Stanford Linear Accelerator Center (SLAC). A charge of $2.5 \cdot 10^{11}$ electrons per pulse at 45 GeV and 30 Hz was routinely delivered for the E-158 commissioning run in April and May, 2001. We have calculated that energies and charges of 45 and 48 GeV with $6.5 \cdot 10^{11}$ and $4.5 \cdot 10^{11}$ particles respectively can be delivered in 370 and 280 ns long beam pulses. Beam loading in the linac was compensated by setting the charge distribution according to a slowly decreasing function, chosen to counteract the rising RF slope of the SLED pulse (SLAC Energy Development). Simultaneous operation with the PEP-II B-Factory posed an additional challenge. Beam pulses with up to 50% different energies had to be accelerated in the linac and then matched to the different beam lines. Pulsed devices have been implemented to enable a fast pulse-by-pulse switching between this beam and the PEP-II injection beams. The commissioning and performance of these devices, along with recent beam measurements are described.

1 SETUP

The required high statistics for the E-158 experiment demand the highest possible beam charge from the SLAC linac. This is done by shaping the beam current distribution in a slowly decreasing manner to get beam loading to cancel the raising SLED pulse [1]. The maximum loading is about 8.5% for the $4.5 \cdot 10^{11}$ case and 15 % for $6.5 \cdot 10^{11}$ particles, corresponding to a 600 kW beam at 120 Hz. Any intensity jitter will be seen as energy jitter: +10% change in intensity will give -0.85% variation in energy (at $4.5 \cdot 10^{11}$). In the RF capture section early in the linac, a “phase-bump” was introduced to cancel the phase-loading of the first 40 ns of the beam in the S-band buncher.

Due to dispersion and wakefield effects, the energy change can translate into transverse motion, which must be kept small. Intensity drift was controlled by feedback to the laser of the polarized gun, but the pulse-by-pulse jitter had an RMS value of 1.5%. Special orbit oscillations at the end of Sector 1 (100m) were launched to keep the transverse jitter small.

2 RUNNING TOGETHER WITH PEP-II

The operation together with PEP-II required several hardware modifications and a compromise in the linac lattice, since the energy profiles of the various beams are up to 50% different.

2.1 Pulsed Magnets

PEP-II uses a damped beam from the damping rings (DR), while the high power E-158 beam goes straight ahead, so two pulsed magnets (to and from the DRs) with ceramic chambers had to be installed.

Problems were encountered with the new ceramic chambers, requiring that the magnet gap be enlarged, which in turn required larger power supplies. Covar vacuum fittings at the ends of the ceramic chambers were magnetic, requiring 3% more current to get the same magnetic field. Finally, the pulsed field needed a flat top pulse longer than the timing shifts used to fill all PEP-II buckets. The transverse jitter for the PEP-II beams was about ten times worse ($1.5\sigma_x$) when the magnets were run in pulsed mode, but this was acceptable for PEP-II.

2.2 Injector Changes

Two laser systems for the short and long beam pulses were used. The pre-buncher and sub-harmonic buncher were on for the PEP-II beams. Pulsed corrector magnets at the end of Sector 1 were used to make fine adjustments to the E-158 beam without interfering with the PEP-II beams.

2.3 Linac Lattice Compromise

Figure 1 shows the different energies of the beams along the linac. In Sector 10 (1000m) the difference is more than 50% from 9 GeV to about 15 GeV, and a 90º betatron lattice for the 15 GeV beam pushes the lower energy beam close to the band pass (180º). There are two principle ways to accelerate the beams: (1) each beam gets its energy on a linear slope along the linac (dashed in Fig. 1), which is done by timing the RF early; or (2) all beams are accelerated along the steepest slope and then the lower energy beam coasts (flat lines in Fig. 1) by turning the RF off for this beam.

The advantage of the first method is that the beams stay matched better, but the disadvantage is a large difference (up to 3 mm) in the orbit, which could not be easily steered out, since our steering procedure allows only one lattice, but two beams with different signs (e^+ and e^-).

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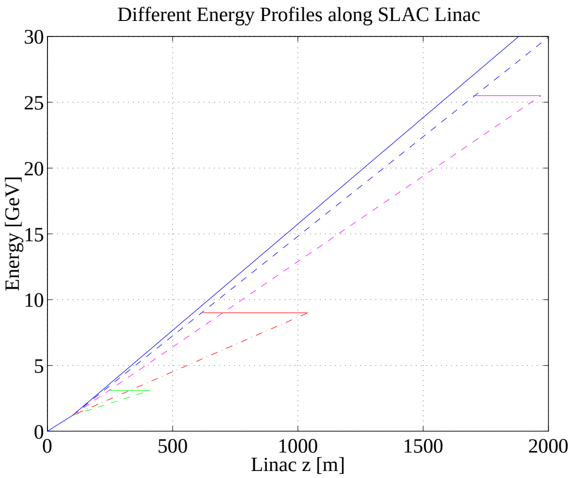

Fig. 1: Energy of the different SLAC beams. The E-158 beam (blue, __) is at 45 (48) GeV at the end of the linac (3000 m) and has the highest energy along the linac. The scavenger beam (magenta, --) ends at 25.5 GeV, the PEP-II beams for filling HER (red, -.) and LER (green, --) have an end-energy of 9.0 and 3.11 GeV.

The second method creates a larger mismatch, but the source of different orbits is more localized and not as large. This second method was used for E-158, and additionally the lattice was set slightly weaker than optimal for the highest energy beam.

3 MEASUREMENTS

Beam measurements were done to check the energy compensation, the energy jitter, and the transverse jitter.

3.1 Energy Compensation

The energy compensation was done by adjusting the intensity and shape of the pulse. The laser intensity for the polarized gun was not sufficient to get the desired current, but we gained about 10 % more current by removing the shaping device (“top hat”). This was still not enough to load the rising slope of the RF SLED pulse (Fig. 2) and get $6.5 \cdot 10^{11}$. More current at the front and less at the end might have achieved this charge. Most of the time we ran with lower charges of $3.5 \cdot 10^{11}$ and $2.5 \cdot 10^{11}$ particles and later on the SLED curve. Measurements were taken with a gated camera looking at the synchrotron light from a bend magnet in the A-Line (Fig. 3).

3.2 Energy Jitter

The energy jitter is dominated by the intensity jitter, as expected from a heavily beam-loaded setup. Fig. 4 shows the correlation. The jitter without the correlation would drop from 0.15% to 0.03% rms. The intensity jitter in this example is actually quite large at 2.5%. The slope indicates beam loading of 5.8%, which is somewhat larger than expected for $2 \cdot 10^{11}$ particles.

An idea to compensate the energy jitter was also tested. It uses the fact that the beam loading changes into a phase variation due to the chicane (before Sector 1).

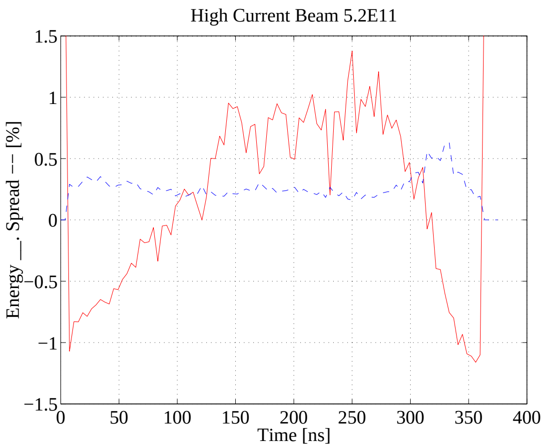

Fig. 2: Measured energy and energy spread of a 350 ns long beam pulse with $5.2 \cdot 10^{11}$ particles. The energy spread of a 60 ns slice is about 0.25%, except at the front and especially the tail of the pulse, where a fast energy drop creates that spread. The beam intensity, which loads the RF, is too low in the front and too high in the back.

Fig. 3: A-Line synchrotron light spot. Higher energy is to the left. The lower energy tail, which curves to the upper right in the middle, is real, while the light rings to the far right are reflections from the shiny beam pipe.

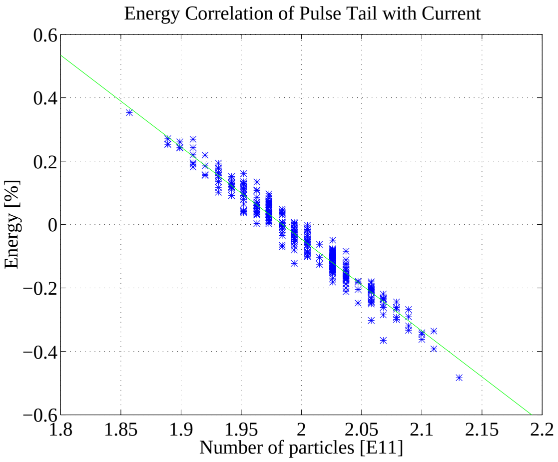

Fig. 4: Beam energy versus current. The beam loading of the high current beam reduces the energy of the tail of the bunch for higher charges: -0.58% for a 10% total charge variation, which is 5.8% beam loading (for 100%).

A higher intensity beam will have a lower energy and will follow a longer path through the chicane, arriving later. When the bunches ride earlier than the RF crest, the tail or later particles will go up the RF slope canceling the stronger beam loading due to the higher intensity. A rough estimate gave a phase offset of about 12° for a perfect cancellation, which is close enough to give measurable results. The measurement (Fig. 5) shows an extrapolated perfect cancellation at 9°, but the single beam energy spread due to the bunch length was too large to get the beam through the energy defining slits. Shorter bunches with an additional compression near the middle of the linac would make it possible to use this effect [2].

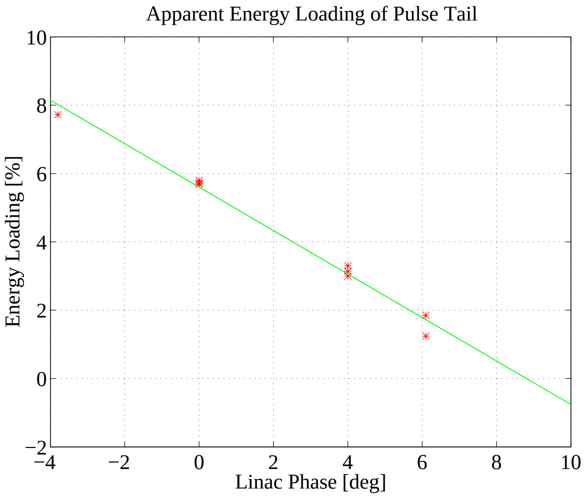

Fig. 5: Measured beam loading for different linac phases. Since the beam loading before the chicane compression is transformed into phase loading, the slope of the linac RF can be used to counteract the loading jitter in the main part of the linac. A +9° linac phase off the crest would reduce the energy jitter totally, but the single bunch energy spread due to the bunch length becomes too large.

3.3 Transverse Jitter

The transverse jitter of the beam is a concern for the experiment and should be less than 10% of the rms beam size. It was found in earlier tests that the jitter, like the energy, is correlated with intensity and can be reduced by introducing betatron oscillations along the linac. This is done with the pulsed magnets at the end of Sector 1. The oscillations are taken out after Sector 20 after the PEP-II related beams have been extracted. Figure 6 shows four different BPMs (beam position monitors) at the end of the linac at a high betatron phase 90° apart. The beam size is about 200 to 300 µm here, and the jitter is good enough when cancelled to 25 µm. A five times smaller intensity jitter of about 0.5% would give this number at nearly all settings. Since the beam blows up in *x* by a factor of seven due to synchrotron radiation in the A-Line, the relative jitter and stability is better in *x* than in *y*. A skew quadrupole might help reduce the *y* plane jitter for the next run.

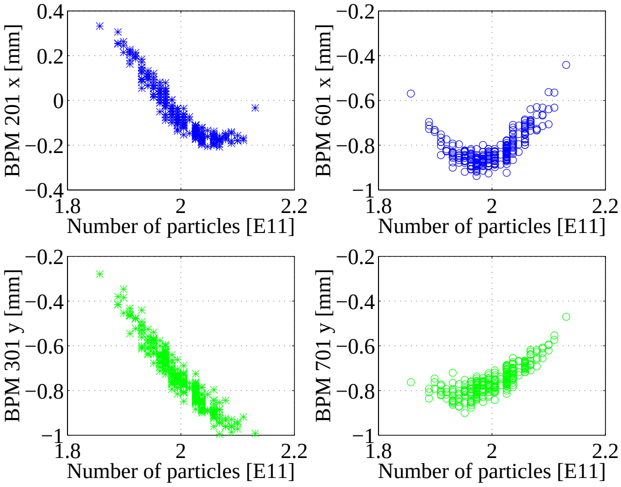

Fig. 6: Transverse jitter at the end of the linac. The jitter in *x* and *y* is strongly correlated with intensity and energy along the linac, because of beam loading. This dispersive jitter can be reduced from of 300 µm to 25 µm rms by launching oscillations early in the linac. A quadratic term is also visible here.

4 BEAM STABILITY

The long-term stability of the beam could be improved. We first thought that the interlaced operation with PEP-II was the cause of instabilities, because any klystron complement change will generate a small lattice mismatch, since each beam sees a different set of klystrons. Then we found that the very first klystron (K02) had multipacting and gave additional jitter, which was later fixed. A day-night variation of the linac phase was recognized after the run and found to be caused by the interferometer of the RF main drive line, which was set to act on pressure and temperature with somewhat inappropriate parameters.

5 SUMMARY

The E-158 beam ran successfully together with PEP-II. This required pulsed magnets and ceramic chambers, and betatron-lattice compromises in the linac. The beam jitter in energy and transverse position was strongly correlated with the 1.5% intensity jitter. The transverse jitter was reduced by a factor of ten with orbit oscillations along the linac. The energy jitter could was reduced with a phase offset. These cancellations varied with time and required frequent attention for optimum performance.

6 REFERENCES

[1] F.-J. Decker, Z.D. Farkas, J. Turner, “High Current, Long Beam Pulse with SLED”, PAC 99, New York, Apr 1999.

[2] P. Emma, private communications.