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TTF2 ACC5 GRADIENT MEASUREMENT

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Abstract

The maximum, measured energy-contribution of ACC5 at TTF2 is 26.5 ± 0.7 MV/m over 7 cavities, each 1.035 m long. For ACC5 gradient measurements, a comparison was made between the beam energy with ACC4 and 5 off and the beam energy with ACC4 detuned and ACC5 cavities 1-7 tuned. The maximum gradient was determined by increasing the amplitude of the RF until the cavity quenched. ACC5 cavities 1-7 were tuned to maximum gradient such that the RF pulse-shape had a flat top. The phase of the RF was, however, 30 ± 10 degrees different from the beam phase for 6 of 7 cavities, producing 12.1 ± 1.5 % less beam energy than on-crest operation would've produced. The beam energy was determined with a beam image on a screen in the dispersive region of the bypass-dogleg and the strength of the upstream dipole.

INTRODUCTION

Beam energy and RF gradient measurements at the TTF2 linac have utilized RF forward power-meters, RF phase and amplitude vector-sums from DSP down-converters [1], photon energy-spectrometers, and screens placed in dispersive regions. For an accurate estimate of the maximum gradient of ACC5, an analysis of the various energy measurements and their error contributions was undertaken.

The most reliable measure of the ACC5 gradient utilized the strength of a dipole (D2BYP) and a beam image on OTR screen (6BYP) to determine the beam energy in the dispersive region of the bypass-dogleg. The beam energy with ACC4 and 5 off was compared to the beam energy with ACC4 detuned and ACC5 cavities 1-7 tuned to resonance. Since ACC4 and 5 are fed power from the same klystron and the tunable power-splitter directing the klystron power cannot eliminate all power going into ACC4, ACC4 must be detuned for measurements of the ACC5 gradient.

The maximum ACC5 gradient was produced by increasing the klystron amplitude until the cavity quenched, subsequently resetting the klystron, increasing the amplitude to the value before the quench, and tuning the module such that the pulse shape had a flat top. Later measurements of the phase of the beam with respect to the phase of the RF revealed an error of 30 ± 10 degrees for 6 of the 7 cavities. This produces 12.1 ± 1.5 % less beam energy than on-crest operation would provide.

The bypass-dogleg, screen-dipole measurement method was cross-checked with a photon energy-spectrometer measurement in the FEL end-station. Due to the good agreement between these two measurements and an analysis of the error contributions from screen-camera misalignment and incoming orbit-offset, this bypass-dogleg screen-dipole measurement is believed to provide a reliable measure of the beam energy, with an error of less than a percent.

The maximum energy contribution of ACC5 at TTF2, given by the direct measurement of the beam energy, is 24.4 ± 0.3 MV/m over 7 modules, each 1.035 m long. Since 6 of the 7 cavities were later determined to be mis-phased for this measurement, the actual gradient, accounting for the phase-error, is 26.5 ± 0.7 MV/m.

SCREEN-DIPOLE ENERGY MEASUREMENT

The alignment of the screen (Fig. 1) in the bypass dogleg (6BYP) is believed to be better than 1 mm, given the techniques used by alignment crews when installing beam-line components. The alignment of the camera to the screen, however, is primarily determined by the machining accuracy and construction of the optical system. It was aligned by hand through line-of-sight, producing an alignment of better than 5 mm [2].

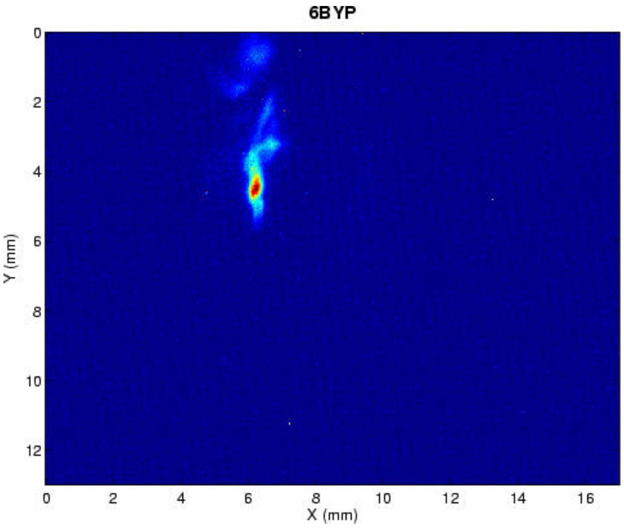

Figure 1: Bypass-dogleg screen image taken directly after an FEL-mode run with SASE. The vertical streak corresponds to 1% energy spread. The beam moves vertically with dipole and beam-energy changes.

The screen is tilted such that, even though the path of the beam is in a coupled, x-y direction, the motion of the beam-center on the screen, produced by energy and dipole-strength changes, is purely vertical.

Incoming-orbit error-contributions were determined to be small because the error is limited by the opening of the collimator (2TCOL) to ±2mm.

The dispersion in this bypass-dogleg section is 204 mm in x and -540 mm in y, for a beam trajectory angle of 20.85 degrees from nominal. For a screen, rotated such that the dispersion is only seen in the vertical direction, the vertical dispersion at the screen is 577.2 mm. For a ±5 mm camera misalignment, the measured energy-offset would then be ±4 MeV for 445 MeV.

The dipole hysteresis error must also be taken into account. The dipole field-strength is assumed to be reliable, but with a hysteresis error contribution of ±1 MeV measured at 358 MeV.

The actual error from screen-camera misalignments, dipole hysteresis, and incoming-orbit error is smaller than ±2 MeV at 440 MeV, as evidenced by the strong agreement between the screen-dipole measurement and FEL-mode energy-spectrometer measurements. For example, at the end of a SASE-FEL run, an energy of 441.5 ± 0.5 MeV was measured with the spectrometer, and after switching the beam from the FEL beam-line to the bypass-line, the energy measured by the screen-dipole method was 440 ± 2 MeV. The error quoted for the spectrometer measurements is the standard deviation over a small sample with the same filter aperture in place and the error quoted for the screen-dipole measurement was given by the energy spread of the beam, since we did not know which part of the beam was lasing.

RF MEASUREMENTS

The RF forward-power and vector-sum were also recorded for each measurement of the beam-energy on the bypass-dogleg screen.

The forward-power is measured by a power-meter attached to a directional-coupler and an attenuator. The error of the power-meter measurement is primarily due to directional-coupler misalignment and cable attenuation and not due to power-meter calibration. In the worst case, this error could be 20% of the gradient measured, and in the best case it would be 5% of the gradient [1], [2] .

In order for the beam-energy to match the energy predicted by the forward power-meter, the beam must be accelerated on the crest of the RF and the RF pulse must be tuned with a flat-top. For the maximum-gradient measurement of ACC5, the phasing condition was not fulfilled for 6 of 7 cavities. The beam was +30 degrees off crest in 3 cavities and -30 degrees off crest in 3 other cavities, reducing the energy-gain in those cavities by 13 ± 2 %. The screen-dipole predicted gradient, 26.5 ± 0.7 MV/m, was 13% less than the power-meter predicted gradient, 31 ± 2 MV/m [2].

The RF phase and amplitude vector-sum measurement was much closer to the beam-energy measured by the screen-dipole method. The vector-sum was at most 3% different from the bypass-dogleg measurement. It measures energy taken out of cavities by the beam, utilizing DSP down-conversion to sum-up phase and amplitude vectors. Over time, the vector-sum read-back has a very small standard deviation because it is maintained by feedback, but as of yet, it has not been completely calibrated.

ACC5 ENERGY CONTRIBUTION

The energy contribution of ACC5 was measured in two different ways. In the quickest method, the beam energies in both bunch compressor 3 (BC3) and the bypass-dogleg were measured with a screen-dipole method. This method was, however, determined to be unrelieable.

Subtracting the bypass-dogleg energy measurement from the BC3 measurement should give the energy contribution of ACC5 with ACC4 detuned. When ACC4 and 5 are off, the same energy should be measured on both BC3 and the bypass-dogleg screens. At ~363 MeV, there was, however, a difference of 15 to 22 MeV between the two screens, as measured on two separate days. The method was unreliable, due to inconsistent positioning of the beam on the BC3 screen, incoming orbit errors, and a likely BC3 screen-camera misalignment. The inconsistent postioning on the BC3 screen contributes ~2 MeV error and possible camera misalignments of 5 mm would contribute ~10 MeV of error from BC3 screen and ~4 MeV from the bypass-dogleg screen. Add a few MeV for dipole hysteresis and incoming-orbit error, and it becomes clear that this method is not accurate enough.

The more reliable measurement used only the bypass-dogleg screen and was cross-checked with the FEL-mode energy spectrometer. In this measurement, ACC4 and 5 were switched off and then the energy was measured in the bypass-dogleg. Then ACC5 amplitude was increased until the cavity quenched. The module was reset and the amplitude increased again to the amplitude just prior to the quench. The RF pulse was tuned to produce a flat-top, and the energy was measured in the bypass-dogleg again. Since this is a relative measurement, using only one screen, the possible screen misalignment becomes irrelavent, and the primary sources of error are the incoming orbit error and dipole hysteresis, contributing less than 2 MeV of error .

CONCLUSION

The maximum energy contribution of ACC5 at TTF2, given by the direct measurement of the beam energy on the 6BYP screen, is 24.4 ± 0.3 MV/m over 7 modules, each 1.035 m long. Since 6 of the 7 cavities were later determined to be mis-phased for this measurement, the actual gradient, accounting for the phase-error, is 26.5 ± 0.7 MV/m. The measurement with the screen is consistent with photon energy-spectrometer, RF power meter, and RF vector sum measurements.

REFERENCES

[1] Thomas Schilcher, TESLA-Report1998-20
[2] Denis Kostin & Rolf Lange
[3] Katja Honkavaara, personal communication.