TEMPORAL CHARACTERIZATION OF ELECTRON BEAM BUNCHES WITH A FAST STREAK CAMERA AT JLAB FEL FACILITY

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Abstract
The design and construction of an optical transport that brings synchrotron radiation from electron bunches to a fast streak camera in a remote area has become a useful tool for online observation of bunch length and stability. This paper will report the temporal measurement we have done and the longitudinal phase space measurement through an imaging optical transport system.

INTRODUCTION

The synchrotron radiation (SR) from relativistic electrons provides a convenient way to measure the bunch length which is one of the most important parameters for the study of free-electron-laser (FEL). Unlike other methods using radiations such as optical transitional radiation(OTR) or Cherenkov radiation, the SR method has no interruption to the running beam, which is highly desired in any type of machine. Streak cameras are very powerful devices especially for fast temporal measurement down to the femto-second scale. They have been used for beam bunch measurement on different accelerator facilities for many years[1-2]. At the JLab 10KW FEL Facility, there are several locations where the bunch length measurement are crucial but has never been done before. In this paper, we report the establishment of optical transport systems and the direct measurement of the bunch length with SR through a fast streak camera. The observed longitudinal phase space with different beam setups will be presented and discussed.

SYSTEM DESCRIPTION

The two locations chosen for the measurement are P1 and P2 in Fig.1, a simplified overall sketch of the Jefferson Lab 10KW FEL facility. The electrons bunches coming from the gun have been accelerated by linac modules at these locations and experienced certain amount of energy spread because of off-crest phase relative to the accelerating radio-frequency field. At P1, the electron trajectories are bent by the first magnetic dipole and then move to the second dipole before they get into ARC1, one of the two 180 degree turning magnets in the facility. The available window ports on these two magnets provide a beam path for the SR light to be observed nearby. The streak camera we have is a Hamamatsu Synchroscan FESCA system with 500 femtosecond(fs) nominal time resolution. Since the SR light has to be well aligned into the entrance slit and the hazardous radiations prevent people from working nearby, we decided to construct an optical transport to a remote area for easy handling of the whole systems.

Fig.2 shows the schematic of the two different optical systems. Due to the beam line structure and surrounding equipment, we have to use several metallic mirrors and two focusing lenses to direct beam out of the accelerator vault. The first three mirrors (M1, M2 and M3) are motorized for remote adjustment because there is no guide light for this transport.
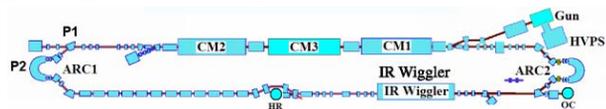

Fig.1. Layout of 10 KW FEL facility. GUN is the photo-cathode electron source. HPVS, high-voltage power supply. CM, Linac Cryomodule. HR, high-reflector. OC, output coupler.
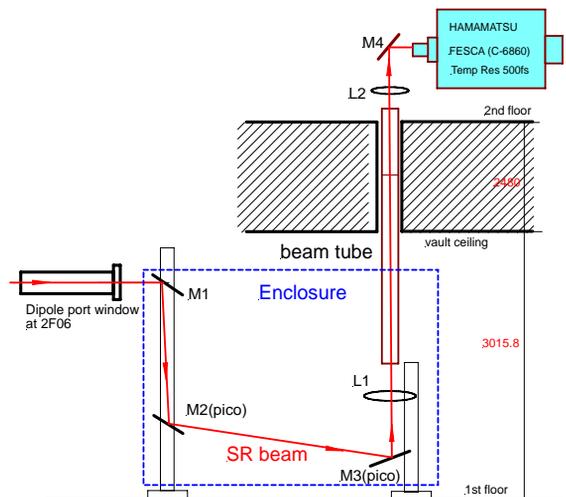

Fig.2. Schematic of the first Optical Transport System (OTS1) after the first dipole. M, flat mirrors. L, lenses.

The optical transport on ARC1 is more complicated and is designed to image-relay the bunch beam profile at the top of ARC1 to the streak camera for longitudinal phase space measurement. This is an all-reflective system consisting of metallic flat mirrors and three concave mirrors with radii of curvature of 200, 500 and 1000mm. In this case, the dispersion induced by optics on the broadband SR beam can be minimized. M1 directs the SR beam from the bunch upwards through an open port to M2. The beam then reflects off several mirrors mounted on a small breadboard fixed on the surface of ARC1. The distance between CM1 and CM2 is adjustable in order to change the overall magnification in order to have a suitable beam size on the camera cathode. The beam propagates through a tube inserted in the penetration. The

final image is formed by a concave mirror CM3. The overall system magnification is about 8:1. A guide HeNe light is available for the rough pre-alignment and the motorized mirrors actually provide the on-line adjustment.
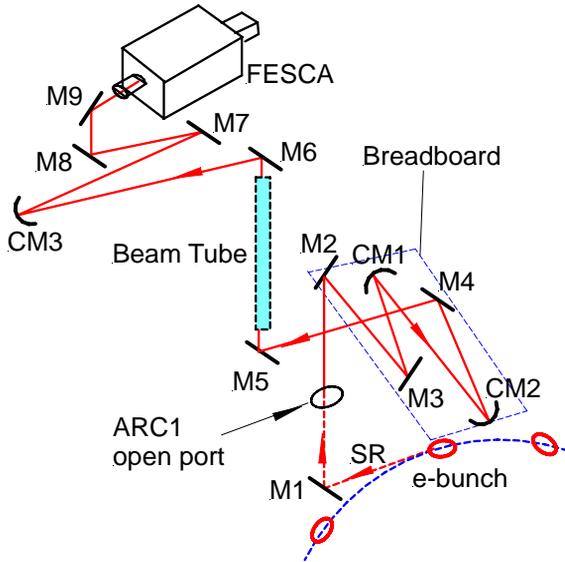

Fig.3. Schematic of the second optical transport system(OTS2). M, flat mirrors. CM, concave mirrors. Detailed description are given in the text.

RESULTS AND DISCUSSIONS

Bunch length measurement

The measured bunch lengths from OTS1 is shown in Fig.4. The pulse width is about 10 picosecond(ps) on average, between 9ps to 13ps, depending on the machine setup. Taking into account the trigger timing jitter, the real bunch length should be a bit shorter.
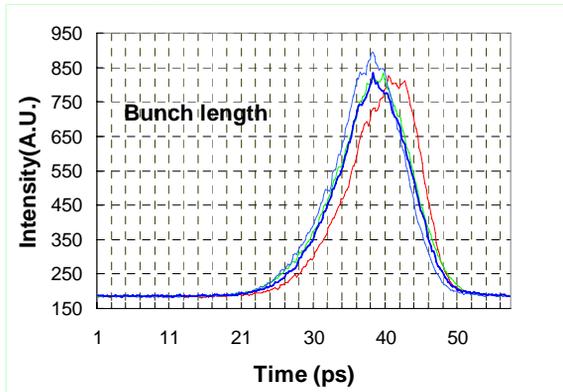

Fig.4. Bunch length measurements from OTS1 for 88MeV beam energy, 9.68MHz CW repetition rate.

Timing Jitter Observation

With a CW running beam, it is easy to measure the timing jitter of the electron bunches by looking the temporal shift with the streak camera. Fig.4 shows a

typical record of pulses randomly captured at certain time interval (about 30 seconds). A few ps (about 2 to 5ps) timing jitter can be easily seen. Further observation tells us the timing jitter largely depends on the time of measurement, machine conditions and the environment. The intrinsic triggering jitter of the streak camera itself is below its time resolution which is less than 1ps in this case. The primary source of timing jitters are the triggering signal from our 37MHz RF module(about 1ps) and the running electron bunches themselves. For a measured 12ps pulse with 3ps jitter, the actual pulse width is about 9.5ps.
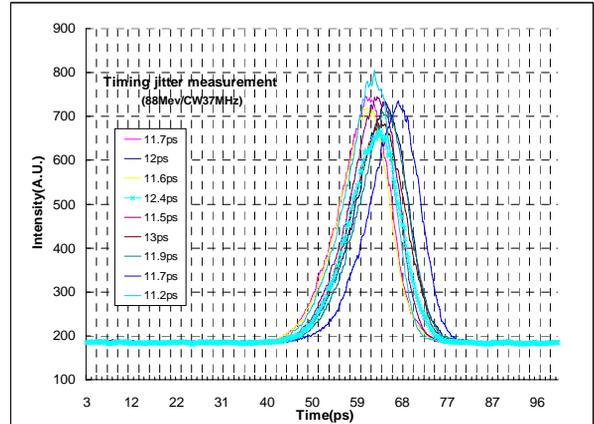

Fig.5. Bunch timing jitter observation for e-beam energy at 88MeV and CW repetition rate 37.4MHz.
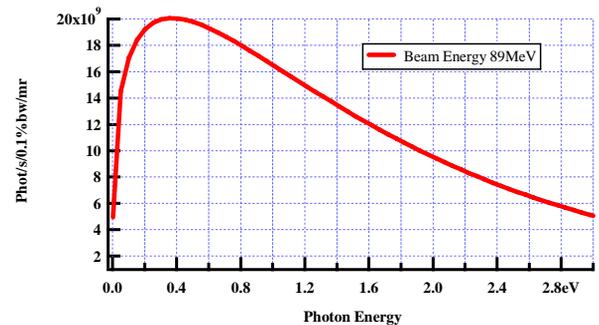

Fig.6. Calculated SR spectrum for 89MeV electron beam in the magnetic dipole. 800nm corresponds to 1.55eV.

Bunch Spectral effect

SR light is characteristically broadband as shown in our case by the calculation in Fig.6. One important effect that tends to lengthen the measured pulse width is the excessive spectral components from the synchrotron radiation. This will give considerable dispersion in the optics such as lenses in the transport system. It is possible to eliminate it with a band-pass filter. Fig.7 shows the data with and without filters. Apparently the pulse length gets shorter while the filter bandwidth becomes narrower. So the real bunch length may well be at least 2 or 3ps shorter than the data obtained without filters. When we have 12ps on the streak camera, the actual bunch will be somewhere around 9ps. This number agrees well with the

calculations by simulation program Pamela with the beam configuration. The filters are all centered at 800nm where the SC has the highest sensitivity and the SR intensity is not far from the calculated spectral peak for both 88MeV beam energy.
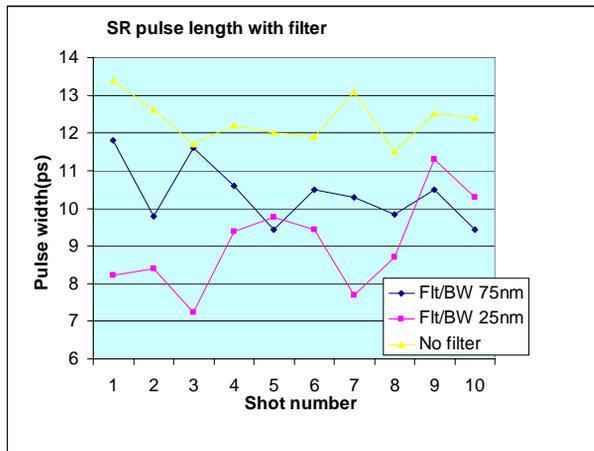

Fig.7. Comparison of bunch length data with and without band-pass filters. E-beam energy is 88MeV, CW beam at 37.4MHz.

Longitudinal Phase Space Observation

OTS1 is basically an imaging system with capability of looking at the bunch image. But the energy spread at the observation position in the dipole is not sufficient to allow a direct longitudinal phase space measurement which nevertheless can be done with one of the 180 degree bending magnet(ARC1). As mentioned before and shown in Fig.3, the optical transport(OTS2) is an all-reflective imaging system. Combined with the streak camera, it provides a straightforward way to obtain the longitudinal phase information. Following are some measurements based on the beam setup available to us at the time of test.
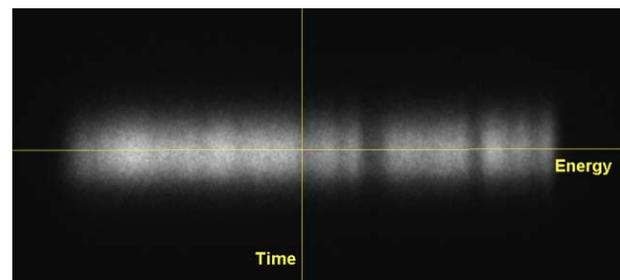
In Fig.8, streak images for different beam setups are shown together with a 20um slit static image. The horizontal axis represents the beam energy spread caused by the bending magnetic field. The tilt of the images clearly shows the change in bunch phase space that corresponds to the different beam configurations. Images in (c) and (d) tilt in the different directions but look symmetric about the energy axis. The image overlaps well with the slit image in (a). The beam energy at the time of measurement was 110MeV with an energy spread of about 2%. The tilt angle depends on the bunch's phase with respect to the accelerating RF field and the magnets that define the electron orbits. Another streak image with the same beam configuration as in (c) and better time resolution (better than 0.7ps as confirmed by a 100fs laser) is shown in Fig.9.

If we take vertical slices over the entire horizontal axis to look at the time duration at different energy positions, they are about 8 to 10ps. No remarkable difference was found. But the fringes along the energy axis can be seen from time to time during the measurement. Examples are given in Fig.10 and Fig.11 with the analyzed data. Even with clear fringes, the temporal distribution along the energy axis is quite uniform. These fringes are definitely not desirable, but the causes for the fringes are not clear at this moment and need further investigation.
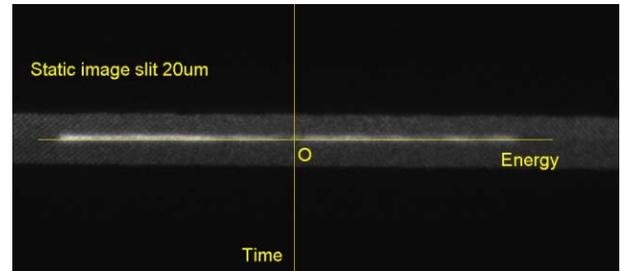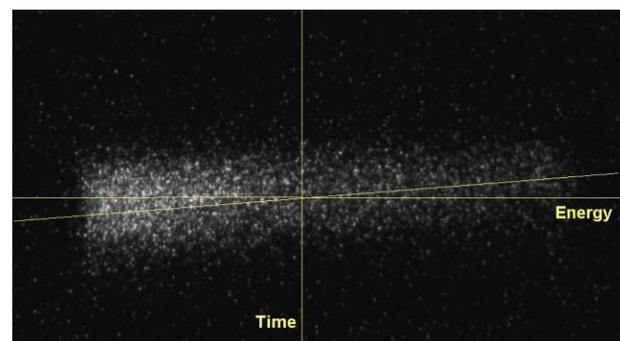

(a)

(b)
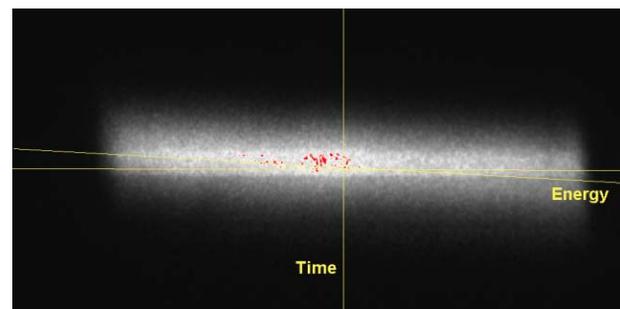
(c)

(d)

Fig.8. Streak images for different beam setups. Higher energy is at the right of the horizontal axis and the down side of the vertical axis is earlier in time.
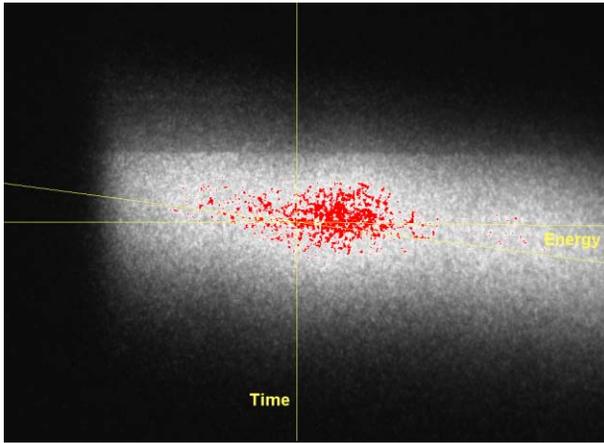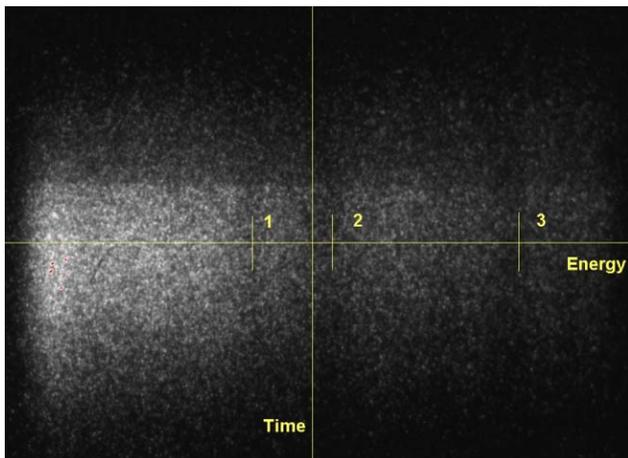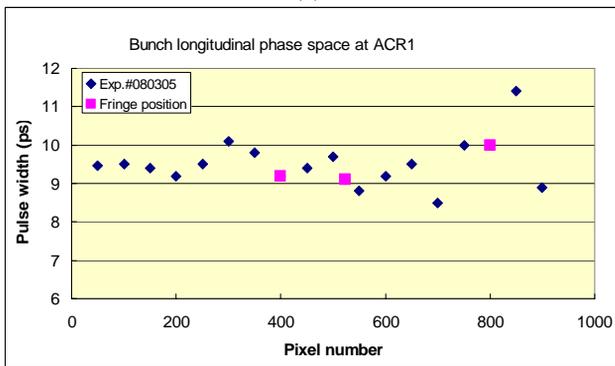
Fig.9. A streak image with fastest time resolution.

(a)

(b)

Fig.10. (a) An typical image from streak camera. The numbers along the energy axis are the fringe positions. (b)Analyzed pulse width (FWHM) along the different energy positions. Pixel number corresponds to beam energy spread. The center pixel (512) is approximately the nominal setup beam energy(110MeV).

Although the measurement recorded the important phase changes, one factor that affects the measurement is the timing jitter which was discussed before. Because the

jitter tends to lengthen the time duration, the real image should be vertically thinner than what we have been shown here. This may also have concealed some of the detailed nonlinear phase information such as phase bending. The solution to this problem is to seek better triggering method or do a single-shot measurement.
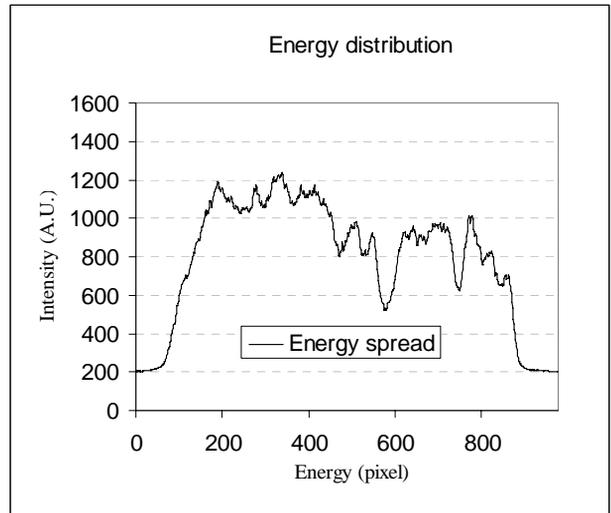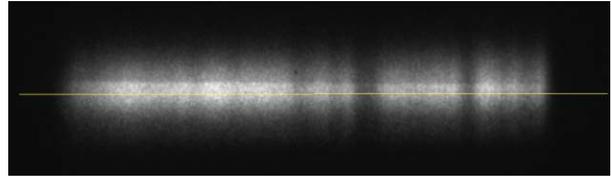

Fig.11. A streak image and the beam energy distribution analysis. The beam configuration is same as (b) in Fig.8.

SUMMARY

By using a fast streak camera with an optical transport system, we performed a bunch length and longitudinal phase space measurement. This work revealed some important bunch information which had never been measured before on our system and tells the way to further system improvements for better precision.

REFERENCES

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[2] M. Uesaka, K. Tauchi, T. Kozawa, T. Kobayashi, T. Ueda, K. Miya, Phys. Rev. **E50**, 3068 (1994).