1 Beam size monitor (IP-BSM)

A nanometer scale beam size monitor (proposed in [1]) was demonstrated at SLAC FFTB during the 1990s[2], measuring a beam size of approximately 70 nm. This IP beam size monitor (IP-BSM) used at FFTB was modified and installed at the ATF2 IP. The IP-BSM uses a fringe pattern formed by two interfering laser beams. The laser fringe pitch is defined by the wavelength (λ) and crossing angle of the two laser paths (θ): $d = \lambda/2 \ \sin(\theta/2)$.

Compton scattered photons from the transverse overlap of the laser fringe pattern with the beam are measured downstream of the IP. The signal modulation depth is written as a function of the IP vertical beam size (σ_y):

$$M = C\,|\cos\theta|\exp\left(-2k_y^2\sigma_y^2\right), k_y = \pi/d, \tag{1}$$

where C expresses the contrast reduction of the laser fringe pattern. Reduction of the laser fringe contrast is caused by deteriorated laser spatial coherency, mismatch in the overlap of the two laser beams *etc.*. Since the modulation depth of the Compton signal is also reduced by C, this is referred to as the modulation reduction factor. From Eq. (1), the beam size is expressed as a function of the modulation depth:

$$\sigma_y = \frac{1}{k_y}\sqrt{\frac{1}{2}\ln\left(\frac{C\,|\cos\theta|}{M}\right)}. \tag{2}$$

We can measure the modulation depth of the Compton signal by measuring its strength for various relative beam positions with respect to the laser fringe. Then, we can evaluate the IP beam size from the measured modulation depth using Eq. (2). For ATF2, the laser wavelength used in the IP-BSM was changed from 1064 nm to 532 nm to reduce the laser fringe pitch, and 3 laser crossing modes (2-8 degree mode, 30 degree mode, 174 degree mode) were prepared to increase the range of possible beam size measurements[3]. The dynamic ranges of the IP-BSM at ATF2 are shown in Fig. 1.

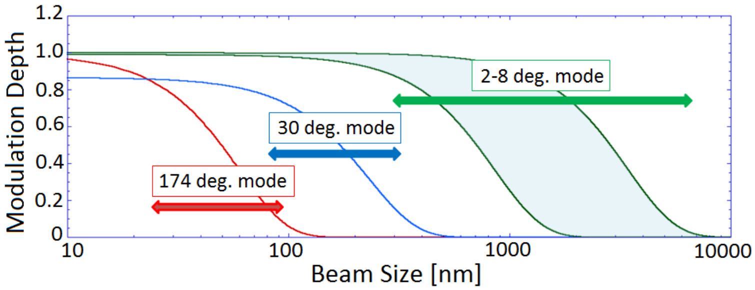

Figure 1: Dynamic ranges of the IP-BSM at the ATF2 IP. Dynamic ranges for 3 laser crossing modes are plotted in the figure.

2 Dynaic intensity dependence reduction with FONT feedback

In the ATF2 beamline, we can generate 2 bunches in the beam pulse train. The bunches are separeted by approximately 300 ns. On the other hand, since the latency of the FONT[4] (Feedback On the Nanosecond Timescale) system is 180 ns , the 2nd bunch orbit can be corrected by using the FONT system. Since the latency of FONT intra-train feedback is faster than the bunch separation of ILC (554 ns for baseline parameter and 366 ns for high luminosity upgrade), the FONT intra-train feedback technique can be applied for ILC. The FONT feedback system consists of the set of BPM and kicker. The beam position of 2nd bunch is corrected by the feedback kicker from the position information of 1st bunch (The position correlation of 2 bunches are greater than 90% for ATF2 beam.).

The schematic layout of FONT system in the ATF2 beamline is shown in Fig. 2. Two FONT systems are prepared in ATF2 beamline. One is the IP feedback system, and another is the upstream feedback system. Since the upstream system has 2 sets of BPM/kicker pair (P2&K1 and P3&K2) and the set of feedback systems are located to be the phase advance by $1/2\pi$, both of the IP position and angle jitters in the pulse train can be reduced by applying the appropriate amplitude to the 2 kickers. It means the

IP angle jitter and the intensity dependence by the IP angle jitter for 2nd bunch can be reduced by using the upstream FONT feeback system.

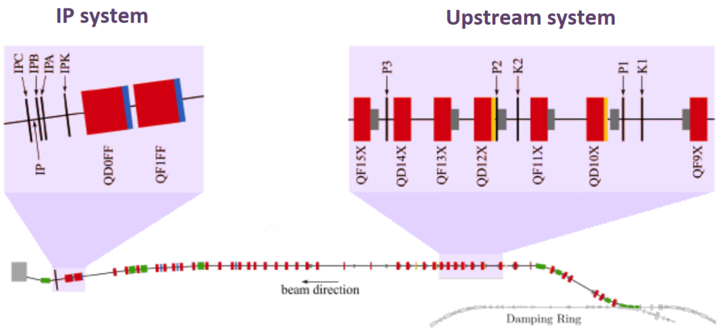

Figure 2: Schematic layout of the FONT feedback system in ATF2 beamline.

In order to enhance the IP vertical angle jitter, the IP vertical beta function was set to be very small to be $\beta_y^* = 25$ μm (large β_y^* optics). The IP angle jitter was evaluated by using BPMs in ATF2 beamlines to be 220 μrad, the IP vertical angle jitter corresponds to approximately 30% of the design IP beam divergence of 693 μrad. Figure 3 shows the result of intensity dependence measurement. The intensity dependence was evaluated to 25.1 ± 1.5 nm/$10^9 e^-$. The IP angle jitter normalized intensity dependence was roughly evaluated to 0.114 nm/$10^9 e^-$/μrad.

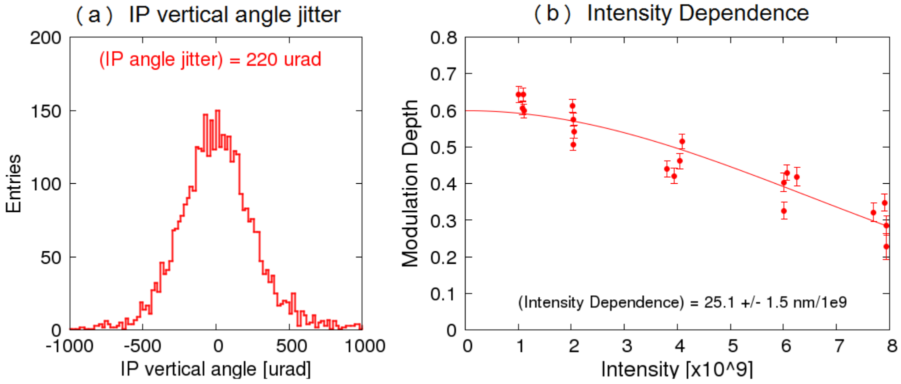

Figure 3: IP vertical angle jitter and intensity dependence for single bunch operation. The IP vertical angle jitter was 220 μrad at the measurement.

The 2 bunch beam operation was started after the intensity dependence measurement. The bunch separation was set to be 304 ns, the correlation of 1st and 2nd bunches was 98% for the bunch separation. Since the beam orbits for 1st and 2nd bunch were different, when the kick angle of the extraction kicker was different, the kicker timing was adjusted to be same beam orbits for 1st and 2nd bunches. The kicker amplitude was also adjusted the beam orbit of the 2 bunch operation to be same orbit in single bunch operation.

The IP angle jitter of 2nd bunch was evaluated to be 215 μrad without FONT feedback, and the IP angle jitter was reduced to be 50.6 μrad with FONT feedback. Figure 4 shows the results of intensity dependence measurement of 2nd bunch with/without FONT orit feedback. Table 1 shows the summary of the IP vertical angle jitters and the evaluated intensity dependence of 2nd bunch. I was found that the dynamic component of the intensity dependence can be reduced by reducing the IP angle jitter by using FONT feedback.

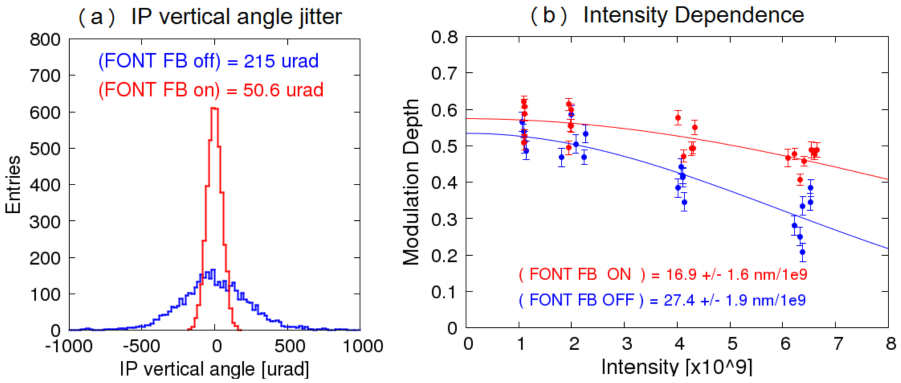

Figure 4: IP vertical angle jitter and intensity dependence for 2 bunch operation with/without FONT orbit FB.

Table 1: Summary of intensity dependence for 2 bunch operation.

	IP angle jitter	Intensity dependence
Single bunch operation	220 μrad	25.1±1.5 $\mathrm{nm}/1 \times 10^9 e^-$
2 bunch operation without FB	215 μrad	27.4±1.9 $\mathrm{nm}/1 \times 10^9 e^-$
2 bunch operation with FB	50.6 μrad	16.9±1.6 $\mathrm{nm}/1 \times 10^9 e^-$

References

[1] T. Shintake, "Proposal of a nanometer beam size monitor for e+e- linear colliders", Nuclear Instruments and Methods, **A311** (1992) 455.

[2] V. Balakin *et al.*, "Focusing of Submicron Beams for TeV-Scale e^+e^- Linear Colliders", Physical Review Letters, **74** (1995) 2479.

[3] T. Suehara *et al.*, "A nanometer beam size monitor for ATF2", Nuclear Instruments and Methods, **A616** (2010) 1.

[4] Reference for FONT upstream FB.