A system of three low-Q cavity beam position monitors (BPMs), installed in the interaction point (IP) region of the Accelerator Test Facility (ATF2) at KEK, has been designed and optimised for nanometre-level beam position resolution. The BPMs have been used to predict an input to a low-latency, intra-train beam position feedback system consisting of a digital feedback board and a custom stripline kicker with power amplifier. The feedback system has been deployed in single-pass, multi-bunch mode with the aim of demonstrating intra-train beam stabilisation on electron bunches of charge ~1 nC separated in time by c. 220 ns. The BPMs have demonstrated a resolution of below 50 nm on the raw measured vertical positions at the three BPMs, and has been used to stabilise the beam to below the 75 nm level. Further studies have shown that the BPM resolution can be improved to around 10 nm on making use of quadrature-phase signals and the results of the latest beam tests will be presented.

The International Linear Collider (ILC) is a proposed linear electron-positron collider with a centre-of-mass energy of 500 GeV [1]. The schematic above shows the 6.7 km circumference damping rings followed by the 11 km long superconducting main linac. The ILC is designed to have a vertical beam size at the interaction point (IP) of 5.9 mm and a bunch separation of 554 ns. The ILC’s final focus system. ATF2’s goal is to achieve a 37 nm beam size with nanometre beam stability as measured at the IP [2].

The Accelerator Test Facility (ATF2) at KEK, Tsukuba, Japan is a test bed for the ILC. The ATF2 consists of a 1.28 GeV electron linac, a super-low emittance damping ring and a scaled version of the ILC’s final focus system. ATF2’s goal is to achieve a 37 nm beam size with nanometre beam stability as measured at the IP [2].

The feedback on Nanosecond Timescales [FONT] [3] project works towards ATF2’s high stability goal by performing intra-train beam-based feedback. Operating with 2-bunch trains at a bunch separation of 215.6 ns, the FONT system uses a beam position monitor (BPM) to measure the path taken by the first bunch in order to then correct the path of the second bunch.

**BPM Resolution Results**

The BPM resolution of the three BPM system (IPA, IPB and IPC) is estimated by predicting the beam position at IPC from the beam position measurement at IPA and IPB. Two methods are used to predict the position at IPC:

**Geometric**

\[ y_{IPC} = a_1 y_{IPA} + a_2 y_{IPB} \]

\( (a_1 \text{ and } a_2 \text{ obtained from transfer matrices}) \)

**Fitting**

\[ y_{IPC} = c_1 y_{IPA} + c_2 y_{IPB} + c_3 \]

\( (c_1, c_2, c_3 \text{ obtained by linear regression}) \)

The residual of the measured and predicted positions at IPC is calculated for each pulse, and the standard deviation \( \sigma \) of the residuals is computed. The resolution is then [6]:

\[ \text{Resolution} = \frac{\sigma}{\sqrt{a_1^2 + a_2^2}} \]

**Method** | **Resolution (nm)**
--- | ---
Geometric | 49.5 ± 0.7
Fitting \( Q' \) & constant | 15.4 ± 0.7
Fitting \( Q', Q'' \) & constant | 14.1 ± 0.6
Fitting \( Q', Q'' \), \( \sigma \) | 13.4 ± 0.6

The results show that a base resolution of around 50 nm can be achieved using the geometric method. Transitioning to fitting \( Q' \) (proportional to beam position) brings the resolution down by a factor 3, and including \( Q'' \) (orthogonal to \( Q' \)) and \( \sigma \) (charge) to the fit brings the resolution down further to the order of 10 nm.

**Feedback Results**

| Feedback | Bunch 1 jitter (nm) | Bunch 2 jitter (nm) |
--- | --- | ---
Off | 412 ± 29 | 420 ± 30
On | 389 ± 28 | 74 ± 5

Operation of the feedback system stabilises the position jitter of the second bunch from 420 nm to 74 nm. Given the incoming values for the jitter of the two bunches and the bunch-to-bunch position correlation, the feedback is expected to stabilise the beam jitter to 79.4 nm [9], which agrees with measurement.

**References**

[1] International Linear Collider: www.linearcollider.org/ILC/
[8] TMD Technologies: www.tmdtechnologies.co.uk/