CLIC BEAM POSITION MONITOR TESTS

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ABSTRACT

Prototype CLIC beam position monitors (BPMs) have been tested in the CLIC test facility (CTF) using a 50 MeV, 1 nC single bunch beam. The test set-up consisted of two BPMs and a charge normalization/phase reference cavity. The detection electronics consisted of a 5 channel super-heterodyne receiver to give charge independent horizontal and vertical positions in each BPM. Data were taken and processed at the full 10 Hz CTF repetition rate using a PC running LabVIEW. Both BPMs were mounted on 0.1 µm resolution micro-movers for displacement calibration. Separate tests in the lab of both cavities and electronics have shown that the potential resolution of the BPM system is less than one micron. An upper limit on resolution of ±4 µm has been demonstrated directly with the CTF beam. The measurement was almost certainly limited by the shot to shot angular jitter of the CTF beam.

1. INTRODUCTION

The strategies currently envisaged for the beam based alignment of the CLIC main linac place strong demands on the performance of BPMs. Beam dynamics simulations indicate that the electrical centers - position of zero beam displacement reading - of the BPMs must be aligned to a locally straight line with a standard deviation of less than 5 µm, and that the BPM resolution must be better than 0.1 µm [1].

The proposed CLIC main linac BPM is based on a 30 GHz TM_{110} mode resonant cavity [2]. Horizontal and vertical positions are given by the excitation of the two polarizations of the TM_{110} mode. The two polarizations are coupled to four waveguides via irises spaced by 90° around the circumference of the cavity. Each pair of diametrically opposite outputs feeds a magic T. A high degree of common mode rejection is obtained by the resonant character of the BPM, by symmetry discrimination in the magic T's, and by the use of a narrow band detection system [3].

The precision of the BPMs is obtained through a carefully controlled manufacturing process based on diamond turning on ultra-precision lathes. The resonant cavity and the external mechanical reference surface are diamond turned during the same machine set-up, an important detail that allows the potential precision of the BPM to be very high.

A program of testing individual components and subsystems has demonstrated that a system resolution of below 0.1 µm can be achieved. Antenna measurements of a brazed test BPM (but without vacuum waveguide flanges) have shown that the electrical center and the mechanical reference surface can be aligned with an accuracy better than 5 µm [4].

The aim of the experiment described in this paper was to test the complete BPM system in an actual accelerator environment. The experiment was made in the CTF using a 50 MeV single bunch beam of roughly 1 nC total charge. Two BPMs were tested simultaneously to remove correlated beam jitter because it was known that the CTF beam jitter was of the order of a hundred microns.

2. TEST CONFIGURATION

The two prototype BPM cavities used in this test were fabricated using the same technology as that developed for CLIC main linac accelerating sections. The copper parts were diamond turned with a tolerance of ±1-2 µm and were then brazed together. Each BPM cavity was coupled to its output WR-28 waveguides via wire machined 1 mm wide coupling irises. After machining, the absolute position of each iris edge was within ±2 µm - thus defining the tolerance on iris width, position, and relative angle. The total spread in the resonant frequencies of the two polarizations of the TM_{110} mode of the two completed BPMs was 4 MHz. The reference cavity was manufactured in the same way as the BPMs but using parts with looser tolerances.

The connection of diametrically opposite outputs of the BPM cavities to the symmetric inputs of the magic T was made via selected pairs of ceramic vacuum-air windows and waveguide runs. The criterion for the selection was that the difference in the phase lengths of the two runs was less than 5°. The detection electronics were located outside the CTF bunker and were connected to the magic Ts by approximately 12 m long waveguide runs.

The 30 GHz vertical and horizontal signals from each BPM, together with the signal from the reference cavity, were mixed down to 120 MHz using a crystal controlled Gunn diode source. At 120 MHz, the signals were amplitude detected. In addition, the sines of the phases of the vertical and horizontal signals with respect to the reference cavity were measured so as to obtain the signs of the displacements. The amplitude and phase signals were routed to low noise sample-and-hold circuits with hold times of 100µs. These signals were then digitized with a scanning ADC controlled by a PC running software written in LabVIEW. Normalization of the horizontal and vertical signals by the reference signal and conversion into a reading proportional to displacement were achieved in the software.

Each BPM was independently mounted on micro-movers which provided 0.1 µm step horizontal and vertical displacements. The centers of the two BPMs were separated by 176 mm. The BPM test assembly was mounted in the CTF about 2.5 meters downstream of the 3 GHz accelerating section. The 50 MeV beam was focused down to a diameter of about 2 mm to pass through the 4 mm internal diameter of the two BPMs and the reference cavity. A schematic drawing of the test set-up is shown in figure 1.

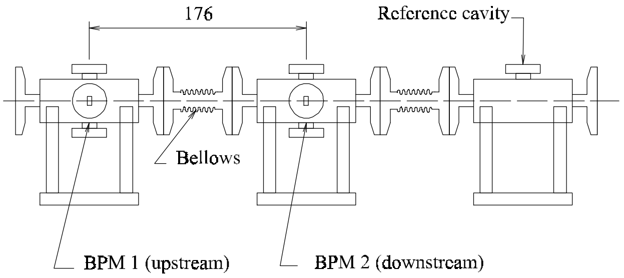

Figure 1: Test set up. From left to right BPM 1, BPM 2, and the reference cavity.

3. MEASUREMENTS

Before data taking began, the BPMs were moved several hundred microns off center in a known direction to provide a clear displacement signal. Appropriate cable lengths were inserted in the 120 MHz signal paths so that the sine detectors gave correct displacement signs.

After this procedure, a large variety of CTF beam optics configurations was tried in an effort to find the best data taking conditions. Due to limitations in beam optics, steering and jitter, good beam conditions could be found for only certain combinations of measurements, for example: only horizontal measurements in both BPMs or horizontal and vertical measurements in only one BPM. When an appropriate beam set-up was found, data were taken. Data from selected runs are shown in Figures 2 to 6. All amplitude data are normalized by the reference cavity voltage, resulting in a vertical scale linear in beam position and independent of charge and bunch length.

The amplitude output for a horizontal scan of 7 20 µm steps of BPM 1 is shown in figure 2. The cavity was scanned so that the beam passed through the center of the cavity. This can be seen by the voltage minimum in the center of the scan and in the 180° phase change in the corresponding phase plot shown in figure 3. The CTF repetition rate was 10 Hz so that the total time for the measurement was roughly 70 seconds.

The jitter of the CTF beam dominates this data and thoroughly obscures the expected sub-micron BPM system features. The BPM system does however provide a very good measurement of beam jitter - as little as ± 10 µm at the beginning of the data taking but with jitter and drift increasing as data taking proceeded.

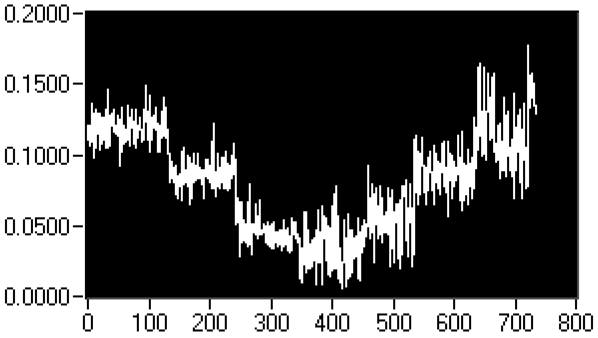

Figure 2: Horizontal output voltage of BPM 1 plotted against shot number. The steps correspond to 20 µm horizontal displacements of the BPM.

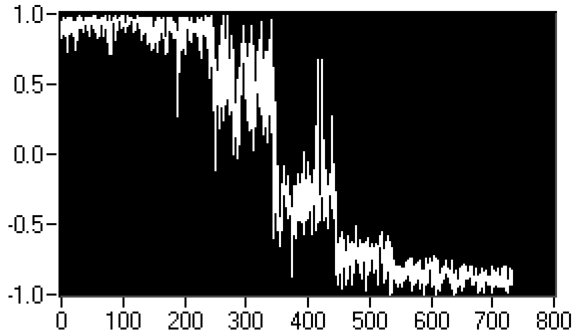

Figure 3: Corresponding plot of sine of phase between BPM and reference cavity.

The effective improvement obtained by using two BPMs and simultaneously taking data in both is demonstrated in the following data. The vertical data from the two BPMs are shown in figure 4. BPM 1 was moved by 25 µm during data taking. The same vertical data of the two BPMs, now plotted one against the other shot by shot, are shown in figure 5. The ± 12 µm jitter visible in figure 5 has been reduced to roughly ± 5 µm. The remaining uncorrelated jitter was not anticipated but was almost certainly due to shot to shot angular jitter of the CTF beam. This hypothesis could not be independently verified during the run but is supported by the relatively large (computed) divergence of the beam in the BPM set-up [5], .85 mrad, compared to the angular jitter, .06 mrad (10 µm at the BPM spacing, 176 mm). This issue is expected to be unambiguously resolved in a future BPM test with the two BPMs spaced approximately 10 mm apart.

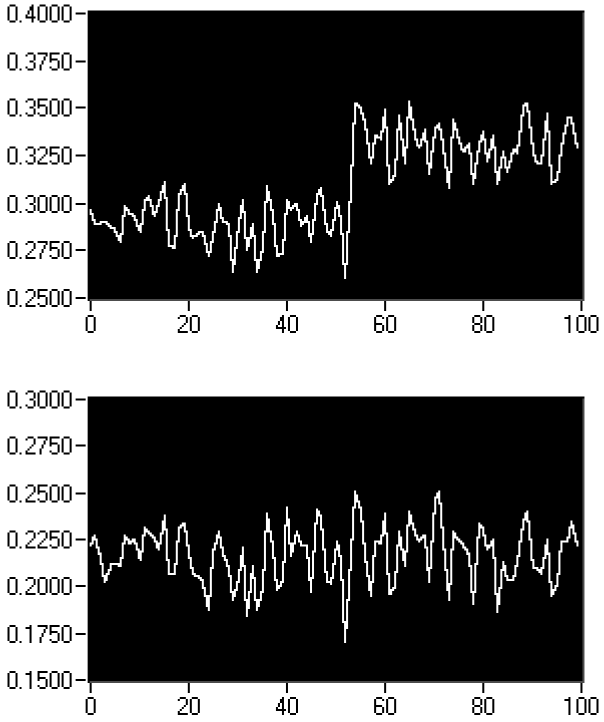

Figure 4: Vertical output data from BPM 1 and 2 respectively with a 25 µm step in BPM 1.

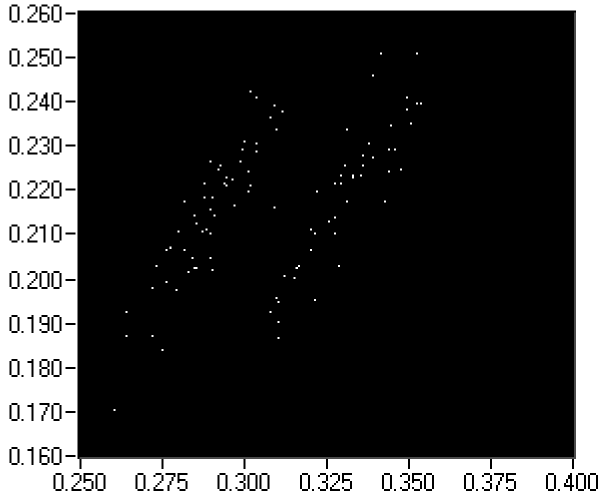

Figure 5: Output of BPM 1 plotted against the output of BPM 2.

The data in figure 5 can still be used to provide an upper limit on the resolution of the BPM by assuming that each BPM contributes an independent random position error. The upper limit on BPM resolution derived in this way is ± 4 µm. It must be emphasized however, that the true BPM resolution is almost certainly in the nanometer range and these results are probably an artifact of specific beam conditions.

Correlation data taken over a large range with three steps in the vertical plane are shown in figure 6.

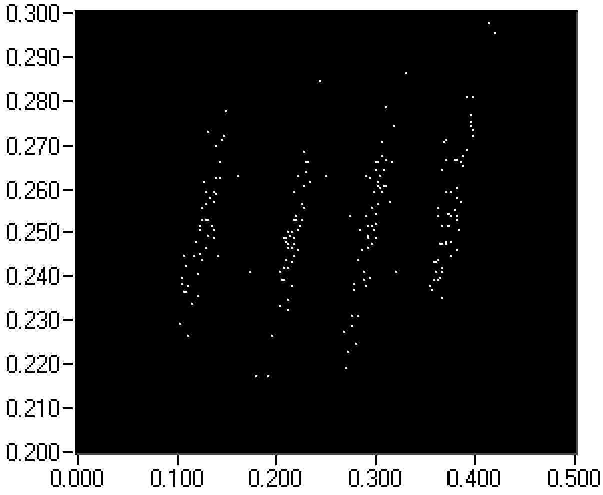

Figure 6: Correlated output with three 50 µm steps.

4. CONCLUSIONS AND FUTURE TESTS

During development all of the components: cavities, magic tees, waveguide runs, and electronics of the CLIC BPM system have been separately tested to be sure that each is consistent with sub-tenth-micron resolution.

This test in the CTF has provided a direct demonstration that the entire system functions reliably in an accelerator environment and has provided an opportunity to refine the measurement techniques that will ultimately be used to measure the BPM system resolution.

The upper limit on system resolution of ± 4 µm has been determined, which is well below the level of CTF beam jitter. However, because this value remains well above the desired demonstration of 100 nm system resolution, a further, improved experiment is planned for 1996 in CTF2.

5. ACKNOWLEDGEMENTS

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