# In Vacuum High Accuracy Mechanical Positioning System of Nano Resolution Beam Position Monitor at the Interaction Point of ATF2

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# IN VACUUM HIGH ACCURACY MECHANICAL POSITIONING SYSTEM OF NANO RESOLUTION BEAM POSITION MONITOR AT THE INTERACTION POINT OF ATF2*

Philip Bambade, Frédéric Bogard, Patrick Cornebise, Sandry Wallon, LAL, Orsay, France
Oscar Blanco, LAL, Orsay, France and CERN, Geneva, Switzerland
Toshiaki Tauchi, Nobuhiro Terunuma, KEK, Tsukuba, Japan

*Abstract*

ATF2 is a low energy (1.3GeV) prototype of the final focus system for ILC and CLIC linear collider projects. A major goal of ATF2 is to demonstrate the ability to stabilise the beam position at the interaction point, where the beam can be focused down to about 35 nm. For this purpose, a set of new Beam Position Monitors (BPM) has been designed, with an expected resolution of about 2nm. These BPMs must be very well aligned with respect to the beam, at the few micron level, to fully exploit their fine resolution. In this paper, the mechanical positioning system which has been developed to enable such a precise alignment is presented. It is based on a set of eight piezo actuators with nanometer range displacement resolution, mounted in a new specially made vacuum chamber. Due to the expected resolution of the piezo actuators, this system also brings a new functionality, the possibility to calibrate the BPMs by mechanically scanning the beam.

## INTRODUCTION

Achieving high luminosity at future linear colliders depends critically on the ability to maintain the two tightly focused beams stably in collision at the interaction point. This is achieved combining careful mechanical designs of the mechanical supports, along the whole system and especially for the last set quadupoles in the final focus, with a number of feedback and feedforward techniques, based on vibration measurements and, ultimately, on measuring the beam itself with high accuracy.

ATF2 is an international project to build and operate a test facility for the final focus of future linear colliders, where the main beam control and instrumentation techniques needed to produce and maintain a stable beam focused with a vertical beam size of a few tens of nanometers are pursued [1]. As significant headway has been made in the past year towards achieving the first project goal of ATF2 (demonstration of 37nm vertical beam size at focal point) [2], attention is now shifting to the second project goal (demonstration of beam stability with 1-2 nm accuracy at focal point, using feedback methods).

## R&D FOR BEAM STABILITY AT ATF2

Unlike a linear collider where information on the relative position of the colliding beams can be inferred from the strong electromagnetic deflections resulting from any residual offset at the IP [3], at ATF2, the beam position must be measured directly with the necessary accuracy. This is achieved through a triplet of nm-resolution cavity beam position monitors (IP-BPMs) [4], two of which will be installed 8cm and 16cm upstream of the IP, and a third one 8cm downstream, in a setup compatible with the operation of the Beam Size Monitor (BSM), the instrument used to measure the vertical beam size of ATF2 down to a few tens of nm, by recording the rate of Compton scattered photons as the beam is scanned across the fringe pattern from two interfering laser beams [5].

Beam stability will be pursued at several levels. As the beam is focused to the nominal beam size of a few tens of nm, it must be stable to better than about 10nm to minimize smearing contributions during BSM measurements. Stability can be checked explicitly by measuring beam jitter in one of the IP-BPMs after moving the beam waist there. For corrective action, the beam position at the IP must then be inferred pulse-by-pulse from the set of IP-BPMs, to either correct the BSM fringe scan data or the subsequent pulses, or bunches, of the beam, through feedback [6]. For the more ambitious 1-2 nm beam stability demonstration of the second goal, the beam position will also need to be measured at one of the IP-BPMs after moving the waist there, while the two other ones are used to infer the position at that location, as input to the feedback. Upstream beam position monitors can also be used for stabilization [6]. Improved stability can then be checked at the IP by moving the beam waist to one of the IP-BPMs. However this does not correct for sources of beam jitter downstream of the corresponding system.

Depending on the time-scale of the beam motion to be stabilized, the feedback can be applied pulse by pulse, at a rate of 3 Hz, or in a multi-bunch mode in which up to three bunches separated by about 150 ns are extracted from the damping ring on the same pulse, also at 3 Hz. The latter mode involves fast IP-BPM readout and electronic processing [4], a fast kicker to deflect the beam and fast computations of the IP-BPM signals, to enable corrections within 150 ns [7].

To exploit the IP-BPMs for stabilization at the nm scale, their resolution must first be studied. The resolution

*bambade@lal.in2p3.fr


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can be measured by analyzing the correlations between the signals recorded at the IP-BPMs as the beam position changes pulse by pulse due to various jitter sources upstream. At the simplest level, one can compare the direct measurement of the position at one IP-BPM with that inferred from the measurements at the two others. The best results are obtained taking into account various coupling effects between the different observables.

When inferring the position at one IP-BPM from the others, as needed both for the resolution studies and to compute signals for stabilization and correction, the relative calibration of the different IP-BPM must be known. The required precision depends on the level of angular fluctuations in the beam. Near the IP, the angular divergence of the beam is very large, typically 0.3mrad. For the usual beam jitter observed at ATF2, of about 10% of the RMS of the beam distribution, the relative calibrations must be determined with a precision < $10^{-4}$ / $10^{-3}$ for 1nm / 10nm residual errors on the inferred position, respectively.

## IP-BPM POSITIONING REQUIREMENTS

An important issue for the IP-BPMs is the dynamic range of their electronics: to achieve resolutions in the nm range, beam offset should not exceed 5-10 microns. This must be achieved by careful alignment of the IP-BPMs with respect to the beam line, followed by beam-based alignment. For this purpose, the vacuum chamber and the internal support mechanism should be machined with sufficient precision with respect to convenient external references which can be used in the overall survey of the beam line. The aim is to align the chamber with a precision < 200 μm with respect to the external world, and to pre-position the three IP-BPMs inside with a precision < 50 μm.

To enable beam-based alignment, the position of IP-BPMs should also be remotely controlled, over a range covering the initial alignment and pre-positioning accuracies, in steps significantly smaller than 1μm.

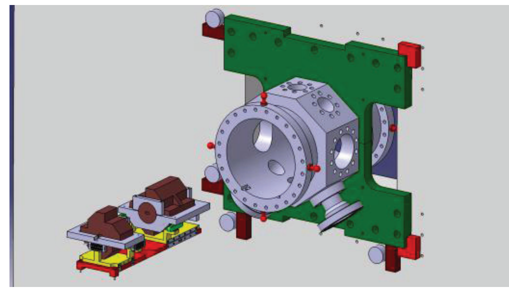
Calibration of IP-BPM can be performed analyzing beam jitter, comparing the magnitude of beam movements directly measured in each IP-BPM with those extrapolated based on reconstruction with other beam position monitors elsewhere in the beam line. Such methods will be pursued, but it is uncertain whether or not they can achieve accuracies in the $10^{-4}$ / $10^{-3}$ range. As an alternative, with a precise enough system of movers, mechanical calibration will also be considered. For that purpose, linearity and reproducibility should be assured at the level of $10^{-4}$ / $10^{-3}$ over the range of motion needed for calibrations.

Other important requirements are those of overall weight, ease of handling, mounting / demounting, vacuum qualification, installation in the vicinity of the IP and compatibility with the BSM. For the latter, a set of viewports for the lasers, as well as the possibility to insert wire-scanners and a mechanical reference target to align the electron and laser beams, are needed.

## MAIN DESIGN FEATURES

Figure 1a,b show a drawing and photo of the completed vacuum chamber. To reduce weight, aluminum was used for the main body, most internal elements and the IP-BPMs.

a)



b)

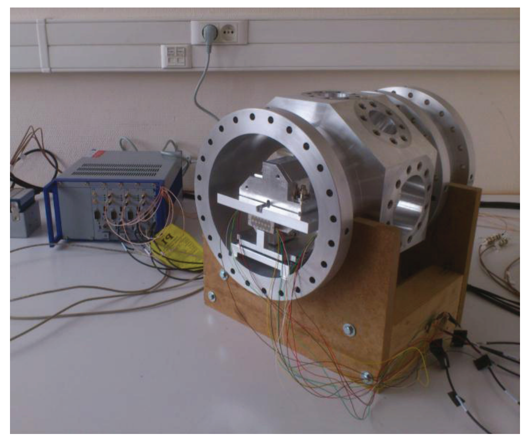


Figure 1: (a) Schematic of vacuum chamber with IP-BPMs, support mechanisms and piezo-movers. The green fixture is for mounting on the BSM vertical optical table. The base plate and IP-BPM cradles are in tripod configurations with precise mechanical references. (b) System with all parts.

A set of eight piezo-movers bought from two companies (PI and Cédrat) are used for lateral and vertical adjustments in the range of about 230 / 300μm, respectively. Strain gauges are used for readback and feedback, with a precision of $10^{-4}$ over the full range. Thermal effects are very important for measurements at the nm level scale, and must be taken into account both for the IP-BPM RF cavities and for the mechanics. A set of in-vacuum PT100 thermal gauges are included on the IP-BPM cradles for monitoring. The control and readout electronics are located outside the accelerator shield, after about 25m of cables.

## TESTING AND QUALIFICATION

Dimensional checks (see Figure 2) were performed to establish space coordinates for the main mechanical references. In addition, the internal positioning system is being measured as part of pre-alignment, by placing shims to absorb residual errors from machining. As part of this process, a special BPM positioning tool was made.

Figure 2: Picture of Mitutoyo 3D machine (precision and resolution of 5/1µm) used for dimensional testing, with the chamber body and special BPM positioning tool at the edge.

The chamber body with flanges and indium sealing was checked for leaks using Helium. Out-gasing of piezo-movers and cables was also found to be adequate for UHV.

An interferometer from Sios (see Figure 3) is used to qualify the performance of the piezo-movers and of the entire mechanical assembly, in particular the closed and open loop stability, the setting accuracy and reproducibility and the calibrations provided by the manufacturers.

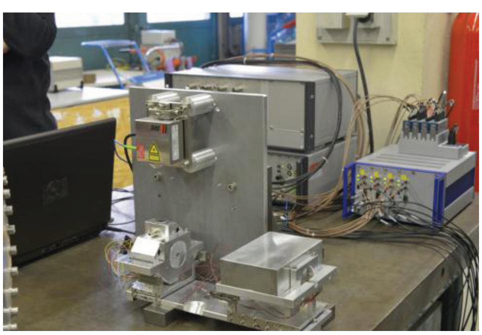


Figure 3: Calibration and stability studies of mechanical assembly with piezo-movers supporting the third IP-BPM.

As an example, the short term vertical stability of the third IP-BPM supported by the tripod of PI piezo-movers is shown in Figure 4, with / without strain gauge feedback. Thermal effects had to be carefully corrected in the analysis. Some resonant vibration was also seen when the whole assembly was tested together with the lateral positioning system. Stiffening the flexible joints involved in that system allowed similar stability performances to be recovered.

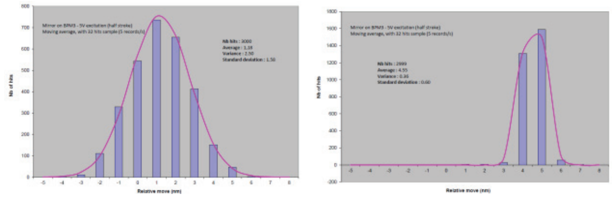


Figure 4: Stability studies of mechanical assembly with piezo-movers supporting the third IP-BPM.

## CONCLUSION AND PROSPECTS

A mechanical system for precise control of the relative position of the IP-BPMs which will be used for the second goal of ATF2 has been designed, built and tested. It is now being prepared for shipment and installation at the IP of ATF2 in July 2013. Many checks and studies will be necessary both during installation and commissioning with beam in autumn, to learn how to make this system work at the required level and to ensure compatibility with the BSM.

## ACKNOWLEDGMENTS

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