PRECISION ALIGNMENTS OF STRIPLINE BPM'S WITH QUADRUPOLE MAGNETS FOR TTF2

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Abstract

Due to the absence of synchrotron radiation in a linac like the TESLA Test Facility (TTF2), it is possible to install the beam position monitors (BPMs) inside the quadrupoles, defining the optical axis of the accelerator. This paper reports on an alignment setup and the procedure, using the stretched wire technique to calibrate the BPMs with respect to the magnetic axis of the quadrupole magnet.

INTRODUCTION

The control of the beam orbit is essential for the operation of linear accelerators for future linear colliders (LC), as well as for free electron laser (FEL) drive linacs. The transport of the beam, by preserving its low emittance, requires a precise measurement of the beam orbit with respect to the magnetic axis of the quadrupoles. As a beam based alignment procedure is not always applicable (common quadrupole power supplies), or sometimes may not give satisfactory results (shot-to shot beam jitter), a stretched wire alignment measurement for quadrupole and BPM pickup can be used as an alternative or add-on.

MEASUREMENT PRINCIPLE

The optical axis of an accelerator is defined by the magnetic axis of the focussing elements, i.e. the quadupoles. Only if the beam is following this axis as close as possible, the machine will achieve optimum performance. Therefore, it is essential to have the BPMs as close and as well aligned to the quadrupoles as possible. Since there is almost no synchrotron radiation in a linac, it is possible to install the BPM inside the quadrupoles without the danger that movements of the vacuum chamber due to heat load will move the quadrupole or the BPM with respect to the quadrupole.

Due to the rigid connection between the two units, it is also possible to determine the offset of the BPM and quadrupole, caused by manufacturing tolerances, before installation on a test bench.
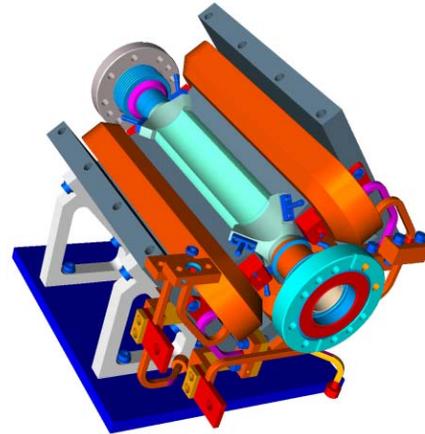

Figure 1: Drawing of a TTF2 stripline installed inside a quadrupole magnet.

The test bench uses a stretched wire, to determine

a) the magnetic axis of the magnets, by measuring an minimizing movements of the wire introduced by current pulses: If a current pulse is passing the wire, while the magnetic field of the quadrupole is present, Lorence force will induce movements of the wire, except if the wire is passing on the magnetic axis.

b) To determine the electrical axis of the BPM within the same reference frame, by using the wire as an antenna for incoupling of an RF signal. This signal is read by two opposite pickups of the BPM. If the wire is exactly on the electrical axis, the difference of the two signals will cancel.

Since we are dealing with no perfect mechanical systems, one has to find the minimum signal for wire movement and antenna signal. The difference of the transverse positions, where the minimum signals are found, is then the BPM offset, to be used as calibration data for the orbit measurement system.

THE STRECHED WIRE TEST BENCH

This idea [1] was already adapted for a few stripline BPM-quadrupole units, used at the S-Band Test Facility linac [2], and is now applied under cleanroom conditions for larger quantities for TTF2.
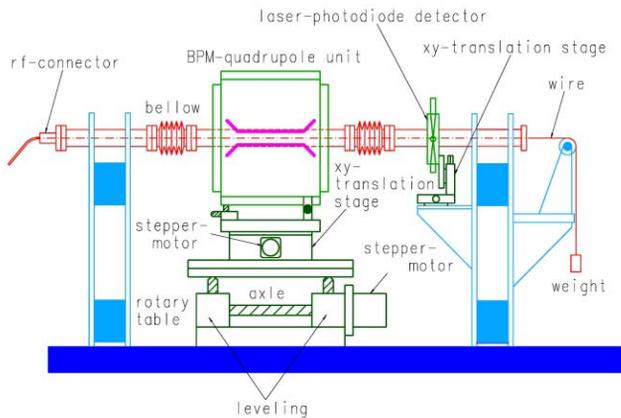
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Figure 2: Schematic view of the stretched wire alignment setup.

Fig. 2 shows a schematic view of the stretched wire test bench with it's basic elements. An aluminium plate carries the BPM-quadrupole unit on a stepper-motor movable xy-translation stage. Two rigid pillars fix the beam-pipe sections, which adapts to the movable BPM pipe in the center via bellows. A 130 µm diameter, copper-beryllium wire is stretched in the center of the beam pipe and forms a coaxial transmission line. The current pulses to measure the magnetic axis, and the rf-signals to find the electrical axis of the BPM are feed from an upstream N-connector. A laser-photodiode detection system, located on the downstream pillar, is used to detect movements of the wire, in order to find the magnetic center of the quadrupole. The distance between this detector and the end of the wire has to be longer than the half of the magnet length, in order to separate signal and reflections. Other parts of the test bench are a defined mass to stretch the wire and some mechanical elements to compensate a tilt between BPM-quadrupole and wire. The laser-photodiode detector can also be moved by a manual xy-translation stage.

The calibration procedure is done in two steps:

CALIBRATION OF THE MAGNETIC CENTER OF THE QUADRUPOLE

A method to measure the effect of a magnetic field on a stretched wire, excited with a strong, but short pulse of charge Q is described in [3], [4]. The *Lorenz* force accelerates the part of the wire, on which the magnetic field B acts, in transverse direction. This displacement of the wire

$$x(z_0,t) = \frac{Q}{2\mu c}\int_{z_0}^{z_0-ct} B(\bar{z})d\bar{z} \tag{1}$$

moves with the wave velocity $c = \sqrt{T/\mu}$ towards upstream and downstream fixpoints of the wire and can be detected at a location z_0 behind the magnet

with the laser-photodiode detector (µ is the weight per unit length of the wire, T is the tensile force to which the wire is stretched).

Before starting the calibration procedure the magnet was cycled using a bipolar power supply. Then the magnet was powered with 25 % of it's nominal current ($\approx$100A). A pulse of 400V, 20A and 10µs lengths was feed into the stretched wire. The magnet was then moved in a way that the signal from the photodiodes gets minimum value. This reading corresponds to the magnetic axis of the quadrupole, and defines the *reference position*.

The movement of the BPM-quadrupole unit was done by computer controlled stepper motors with a resolution of 5µm (hor.) resp. 0.6µm (vert.) Being close to the magnetic center also the tilt between wire and magnetic axis was minimized.

From this reference position –micrometer gauges and step counter are set to zero – we started the second step of the procedure:

CALIBRATION OF THE ELECTRICAL CENTER OF THE STRIPLINE BPM

In this step the wire is used as an antenna to produce RF-signals on the electrodes of the BPM. A difference signal of two opposite electrodes of the stripline BPM was produced by wiring well calibrated, phase-stable semi-rigid coaxial cables and a *M/A-COM H-9* 180° broadband hybrid. With a network analyzer a frequency-domain $|S21(f)|$ measurement was set up between stretched wire and the Δ-signal output. Reflections in the non terminated stretched wire pipe are not important, as the measurement was performed for a single frequency (zero-span mode). By moving the BPM-quadrupole unit with the stepper motors and appropriate settings of the network-analyzer ($f$center = 180MHz, fRBW= 100Hz, $t$sweep= 5s) it was easily possible to minimize $|S21|$ down to the -100dBm noise level. The signal minimum could be identified clearly within a single step in the horizontal (step size: 5µm) and 2..3 steps in the vertical plane (step size: 0.6µm).

When both planes show a minimum of the Δ-signal transfer, the wire was in the electrical center of the stripline BPM. The *xy-offset* between magnetic center of the quadrupole and electrical center of the stripline BPM was evaluated by counting the driven steps, and cross-checked with the micrometer gauge readings.

RESULTS

23 BPM-quadrupole units were calibrated with the stretched wire alignment setup. Each measurement was performed twice, the setup was de-adjusted and partially demounted between individual measurements. The results are shown in Fig. 3. As expected 200...300 µm offsets typical for mechanical construction tolerances show up. While the resolution to identify the BPM center is in the range 1...2 µm, the identification of the magnetic center is

limited to 10...20 µm, dominating the resolution of the complete setup. This is due to several facts, like stray fields, wire diameter, laser focussing, mechanical vibrations, etc. and, in the horizontal plane, the rather large step size of the motor system.
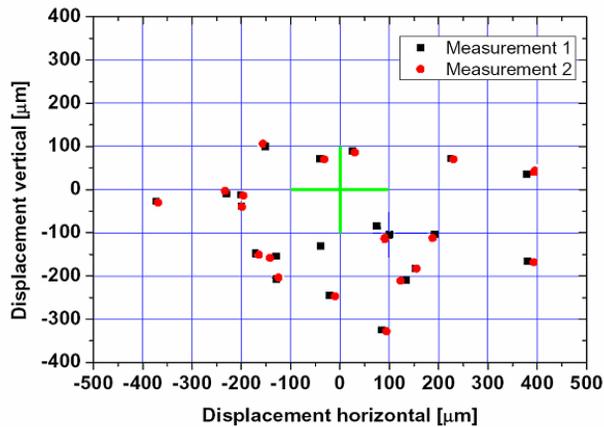

Figure 3: Results of the stretched wire alignment procedure.

The offset data taken by this measurement will be included as calibration data in the BPM readout system.

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